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1960

TABLE OF CONTENTS

1. AKANA, ALBERT K. JR., HERBERT J. MANN and ROBERT E. K. D. LEE
Research vessel is fitted for underwater observation of fish.

2. AUSTIN, THOMAS S.
Oceanography of the east central equatorial Pacific as observed during Expedition EASTROPIC.

3. ______ Summary, 1955 - 1957 ocean temperatures, central equatorial Pacific.

4. BROCK, VERNON E.
Fisheries and the future.

5. ______ The introduction of aquatic animals into Hawaiian waters.

6. ______ and ROBERT H. RIFFENBURGH
Fish schooling: a possible factor in reducing predation.

7. GRICE, GEORGE D. and EVERET C. JONES
Two new species of Candacia (Copepoda: Calanoida) from the central Pacific with notes on two other species.

8. MARR, JOHN C.
The causes of major variations in the catch of the Pacific sardine, Sardinops caerulea (Girard). (Abstract)

9. MATSUMOTO, WALTER M.
The application of paper chromatography in identifying tuna larvae.

10. ______ Notes on the Hawaiian frigate mackerel of the genus Auxis.

11. MCGARY, JAMES W.
IGY oceanographic program and the development concerning the Pacific Equatorial Undercurrent. (Abstract)

12. ______ Surface temperature anomalies in the central North Pacific, January - May 1958.

13. ______ and JOSEPH J. GRAHAM
Biological and oceanographic observations in the central North Pacific, July - September 1958.

14. MURPHY, GARTH I.
Introduction of the Marquesan sardine, Harengula vittata (Cuvier and Valenciennes), to Hawaiian waters.

(continued)

15. ______, KENNETH D. WALDRON and GUNTER R. SECKEL
The oceanographic situation in the vicinity of the Hawaiian Islands
during 1957 with comparisons with other years.

16. NAKAMURA, EUGENE L.
Confinement of skipjack in a pond. (Abstract)

17. OTSU, TAMIO
Albacore migration and growth in the North Pacific Ocean as estimat
from tag recoveries.

18. RIFFENBURGH, ROBERT H.
A new method for estimating parameters of the Gompertz growth curve

19. ______ A system analysis of the marine ecology.

20. SCHANER, EVERETT and KENNETH SHERMAN
Observations on the fecundity of the tomcod, Microgadus tomcod (Wal

21. SECKEL, GUNTER R.
Advection - a climatic character in the mid-Pacific.

22. ______ and KENNETH D. WALDRON
Oceanography and the Hawaiian skipjack fishery.

23. STRASBURG, DONALD W.
A new Hawaiian engraulid fish.

24. ______ Estimates of larval tuna abundance in the central Pacific.

25. ______ and HEENY S. H. YUEN
Progress in observing tuna underwater at sea.

26. ______ and HEENY S. H. YUEN
Preliminary results of underwater observations of tuna schools and
practical applications of these results.

27. VAN CAMPEN, WILVAN G.
Japanese summer fishery for albacore (Germo alalunga).

28. VAN LANDINGHAM, JOHN W.
A note on a stabilized starch indicator for use in iodometric and
iodimetric determinations.

29. YOSHIDA, HOWARD O.
Marquesas area fishery and environmental data, January - March 1959.

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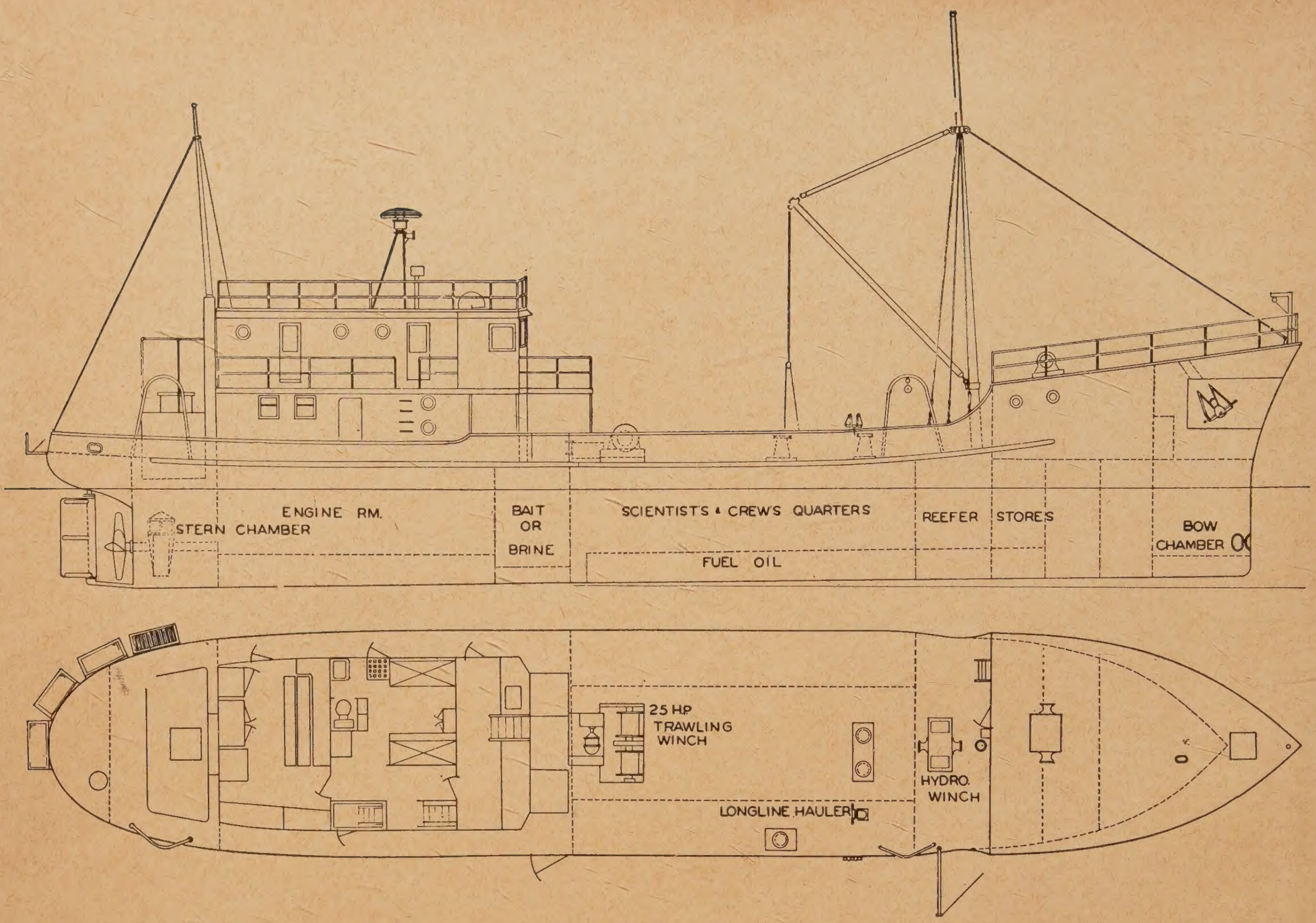
THE CHARLES H. GILBERT



Research Vessel is Fitted For Underwater Observation of Fish

By
Albert K. Akana Jr.
Herbert J. Mann
Robert E. K. D. Lee

• *Charles H. Gilbert,* U. S. Bureau of Commercial Fisheries research vessel attached to the Honolulu Biological Laboratory (HBL), has recently undergone extensive alterations which make her one of the most modern and versatile vessels of her class. The modifications to the vessel, including startling innovations such as an underwater bow chamber for observing fish and a bulbous bow, were accomplished at Gunderson Bros. Engineering Corp. of Portland, Ore., under the direction of L. C. Norgaard and Associates of San Francisco.

Built in April, 1952, by the Tacoma Boatbuilding Co., Inc., Tacoma, Wash. the *Gilbert* has now had two major alterations. The vessel's over-all length was 84′2″ until January, 1954, when a 28′ parallel hull section was added at Colberg Boat Works of Stockton, Calif., increasing over-all length to 112′2″.

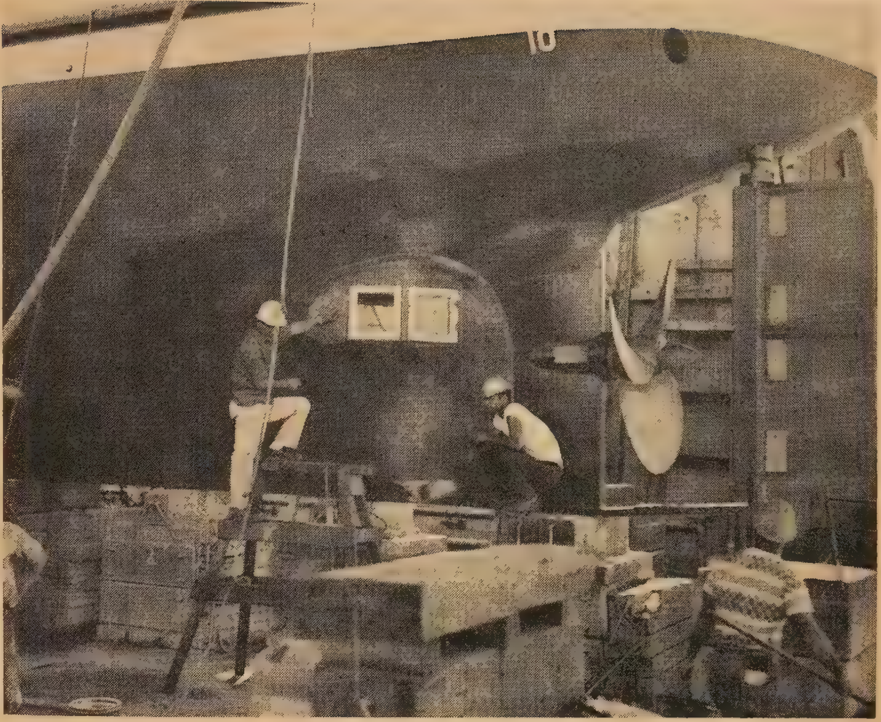
In June, 1959, an underwater viewing chamber was installed at the port quarter, forward of the propeller and directly beneath the fishing racks. This installation, made at the shipyard of the Hawaiian Dredging and Construction Co., Honolulu, followed extensive investigations by HBL staff members of various means for accomplishing underwater observations, including overside ladders and caissons. Excessive turbulence, which hindered the observer's vision, and the cumbersome handling of the equipment were the principal drawbacks of these early installations. The chamber, comfortably accommodating one person, has two glass ports for direct observation of tuna behavior during fishing operations.

NOTE—Authors are members of the staff of the Honolulu Biological Laboratory, U. S. Bureau of Commercial Fisheries, Honolulu, Hawaii. Mr. Akana is marine superintendent; Mr. Mann is fishery methods and equipment specialist; and Mr. Lee is port captain. This article is published by Pacific Fisherman with the permission of the Director, U. S. Bureau of Commercial Fisheries.

Advanced Features of the "New" Gilbert

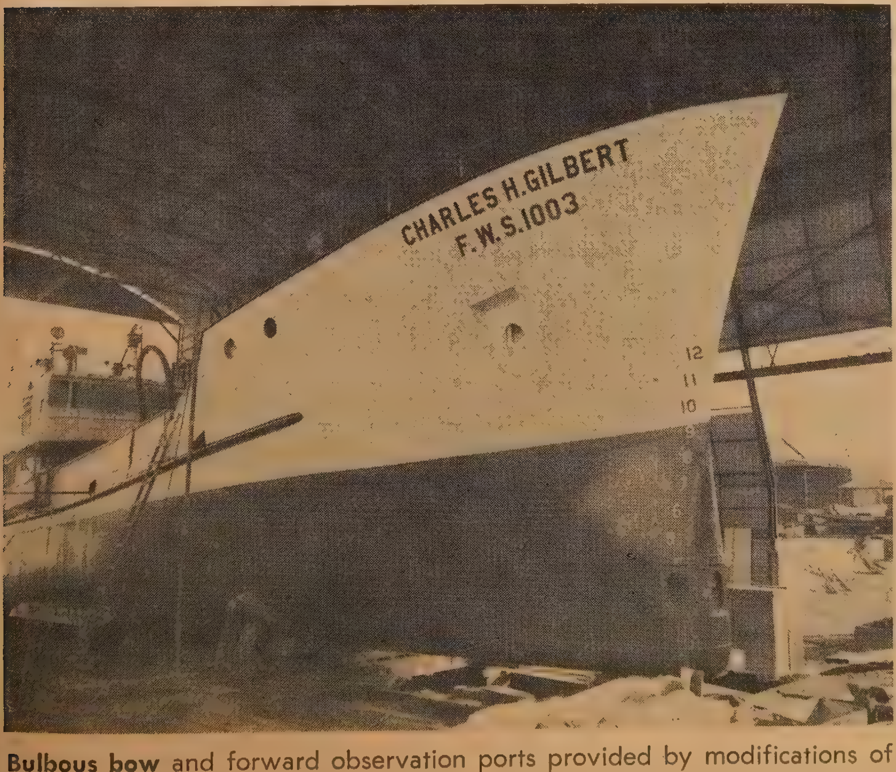
© Several outstanding and advanced features were incorporated in the "new" *Gilbert* during the second major alteration at the shipyard of the Gunderson Bros. during the period November 24, 1959, to March 17, 1960.

As a result of the success of the stern underwater viewing chamber, and to meet the increasing needs of marine biologists in the study of fish behavior, an underwater observation chamber was installed in the vessel's new bow. The original bow was cut away and a new "streamlined" bulbous bow was added. The "bulb" comfortably accommodates a single observer who is able to take notes, movies or photographs of fish action through three 1"x12"x18" oval tempered glass ports which are installed forward, port and starboard 6' below the waterline. Access to the chamber is from a watertight hatch forward of a watertight bulkhead designed to prevent flooding in case of an accident. It is noteworthy that the *Gilbert* is perhaps the first fishery research vessel to be fitted with a bulbous bow and fore and aft underwater observation chambers. It is anticipated that this new approach to research will bring about better knowledge of tuna behavior which may improve or introduce new fishing methods and techniques to increase the efficiency of capturing tuna.



Observation blister on the **Charles H. Gilbert's** hull, permitting underwater observation of tuna behavior while they are being fished from the racks immediately above.

Other alterations include new, air-conditioned, midship quarters; new pilot house with a steering console using Sperry hydraulic system and a new propulsion engine. The vessel is now repowered with a new Caterpillar D397 (Series D) turbocharged marine diesel engine which developed 500 hp. at 1200 rpm. during trials. The new engine is fitted with hydraulically operated 3.79:1 reverse and reduction gears which drive a Coolidge 74½" diameter x 45" pitch 3-bladed, bronze propeller. Engine starting is accomplished by an American Bosch starting system. During a test made over a measured mile, 10.8 knots was maintained at 1100 rpm. with the vessel in a fully loaded condition.



Bulbous bow and forward observation ports provided by modifications of the hull of the research vessel Charles H. Gilbert.

The ship's hold, formerly a stowage area for gear and equipment, was divided into three staterooms; two rooms for use by scientific personnel, each containing two built-in berths, a desk, chair and lavatory and a crew's quarters with six berths and a lavatory. Below deck covering is of vinyl tile.

To equip the vessel for operations in tropical waters, an air-conditioning unit has been installed to serve the hold quarters. This unit is a Delco OU-30A with output capacity of 30,500 BTR/HR. The air supply is led by ducts to adjustable outlets in each of the rooms.

In addition to berthing accommodations in the hold, there are four berths in the main deck quarters and two in the captain's stateroom on the bridge deck. This stateroom is equipped with a desk, chair and lavatory.

The bridge deck house was enlarged aft to provide a room which serves as a library, conference room and dry laboratory. The wheelhouse was extended forward to accommodate a control console which is equipped with a Sperry magnetic compass pilot, Sperry hydraulic steering and Westinghouse controls for the main engine. The flying bridge is also equipped with a control console of similar arrangement. Steering is accomplished by levers.

Other Distinguishing Features

● The vessel is equipped with Sperry rudder indicators, loran and rdf. RCA radar, three transmitters and receiver sets, two fathometers, one of which is capable of recording depth to 6,000 fathoms, a double drum winch for midwater trawling, a longline hauler, a 15-hp. plankton and hydrographic winch, a 7.5-hp. hydraulic powered BT winch and a bait tank aft which was converted into a portable unit.

After completion of the alteration work at the shipyard, the *Gilbert* departed Portland, Ore., on March 18 on a shakedown cruise to San Pedro. Following adjustments to gear and equipment in San Pedro, the vessel departed for a 2-month cruise along the west coast of Mexico and Central America with a complement of 11 crewmen and 4 scientific personnel. She returned to Honolulu, her homeport, on May 23, 1960.

All modifications have proved to be outstandingly successful; those that improve her qualities as a research tool, those that improve vessel operation and those that improve living accommodations. As she now exists, the *Gilbert* is the most modern, versatile research vessel of her class. No additional major modifications are planned.

Reprinted from PACIFIC FISHERMAN, *July* 1960

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OCEANOGRAPHY OF THE EAST CENTRAL EQUATORIAL PACIFIC AS OBSERVED DURING EXPEDITION EASTROPIC

BY THOMAS S. AUSTIN

FISHERY BULLETIN 168
From Fishery Bulletin of the Fish and Wildlife Service
VOLUME 60

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE, Arnie J. Suomela, *Commissioner*

OCEANOGRAPHY OF THE EAST CENTRAL EQUATORIAL PACIFIC AS OBSERVED DURING EXPEDITION EASTROPIC

By Thomas S. Austin

March 3, 1849

FISHERY BULLETIN 168
From Fishery Bulletin of the Fish and Wildlife Service
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CONTENTS

	Page
Introduction	257
Results of oceanographic observations	259
Circulation features	259
Vertical distribution of properties	260
Temperature	260
Salinity	262
Density	264
Oxygen	266
Phosphate	269
Horizontal distribution of properties	269
Surface temperature	270
Depth of thermocline	271
Surface salinity	272
Phosphate	273
Discussion of results	274
Summary	280
Literature cited	281

ABSTRACT

From September 23 to December 17, 1955, the U. S. Fish and Wildlife Service research vessel *Hugh M. Smith* participated in a multiple-vessel oceanographic survey of the eastern tropical Pacific (Eastropic). The results of physical and chemical oceanographic observations made from the *Smith* are described, with emphasis on those observations and results which are of significance to the distribution and abundance of the marine biota.

OCEANOGRAPHY OF THE EAST CENTRAL EQUATORIAL PACIFIC AS OBSERVED DURING EXPEDITION EASTROPIC

By **Thomas S. Austin**, *Oceanographer*
Bureau of Commercial Fisheries

Since early in 1950, the Pacific Oceanic Fishery Investigations (POFI),[1] U. S. Fish and Wildlife Service, has been studying the oceanography of the central equatorial Pacific. These studies have been centered in an area between 140° W. longitude and the 180th meridian and between 12° N. and 10° S latitude. The work has been directed toward determining circulation features and the associated distribution of the marine chemical and physical factors in order to more adequately understand the variations in the distribution and abundance of the biota, especially the yellowfin tuna (*Neothunnus macropterus* Temminck and Schlegel).

The earlier phases of the program were exploratory. As the resulting data were analyzed, the need for specialized studies became evident. One such study involved the east-west variations in the ecology of the northern boundary of the Equatorial Countercurrent; another, an extension of observations along the Equator to the east of 140° W. longitude. These two studies were carried out during a five-vessel, simultaneous survey of the eastern tropical Pacific (Eastropic). The survey extended from 160° W. longitude to the west coast of the Americas and was conducted during the fall and winter of 1955.

Data and descriptions of the circulation features and distribution of the variables in the general area surveyed during expedition Eastropic are available from several sources. These include, in part, the reports of the *Dana* (Thomsen 1937), the *Carnegie* (Sverdrup et al., 1944; Fleming et al., 1945), the *Albatross* (Bruneau et al., 1953), POFI vessels (see Sette et al., 1954; Austin 1957), and unpublished data kindly furnished by the Scripps Institution of Oceanography (SIO) from their operations Shellback and Capricorn.

The currents in the east-central equatorial Pacific are generally zonal (east-west). They include the westerly flowing North Equatorial Current with its southern boundary near 10° N. latitude, the westerly South Equatorial Current with its northern boundary near 5° N. latitude, and the easterly Equatorial Countercurrent in between. Centered about the Equator and beneath the South Equatorial Current is the easterly flowing Equatorial Undercurrent (Cromwell et al., 1954; Fofonoff and Montgomery, 1955).

Five agencies collaborated in expedition Eastropic. Personnel from POFI aboard the research vessel *Hugh M. Smith* (cruise 31) studied east-west variations in conditions along the northern boundary of the Equatorial Countercurrent and along the Equator. Representatives of SIO and the Inter-American Tropical Tuna Commission aboard the Scripps' vessels, the *Spencer F. Baird* and *Horizon*, operated southward from San Diego, Calif., to northern Peru and in the Gulf of Panama. The *B. S. P. Bondy*, assigned by the Peruvian Hydrographic Office, surveyed off the northwest coast of South America in the general area of the Peru Current, and the California Department of Fish and Game vessel, the *N. B. Scofield*, conducted longline fishing in the area studied by the *Horizon* and the *Baird*. The tracks of all the cooperating vessels are shown in figure 1.

The *Smith* departed Honolulu, Hawaii, on September 23, 1955, on a southerly course, crossed the westerly flowing North Equatorial Current and proceeded into the easterly Equatorial Countercurrent. The boundary between the two currents was determined by the variations in the vertical distribution of temperature (ridge in the thermocline at the northern boundary of the Countercurrent) and the change in direction of flow as shown by the geomagnetic electrokinetograph (GEK) until it became inoperative on

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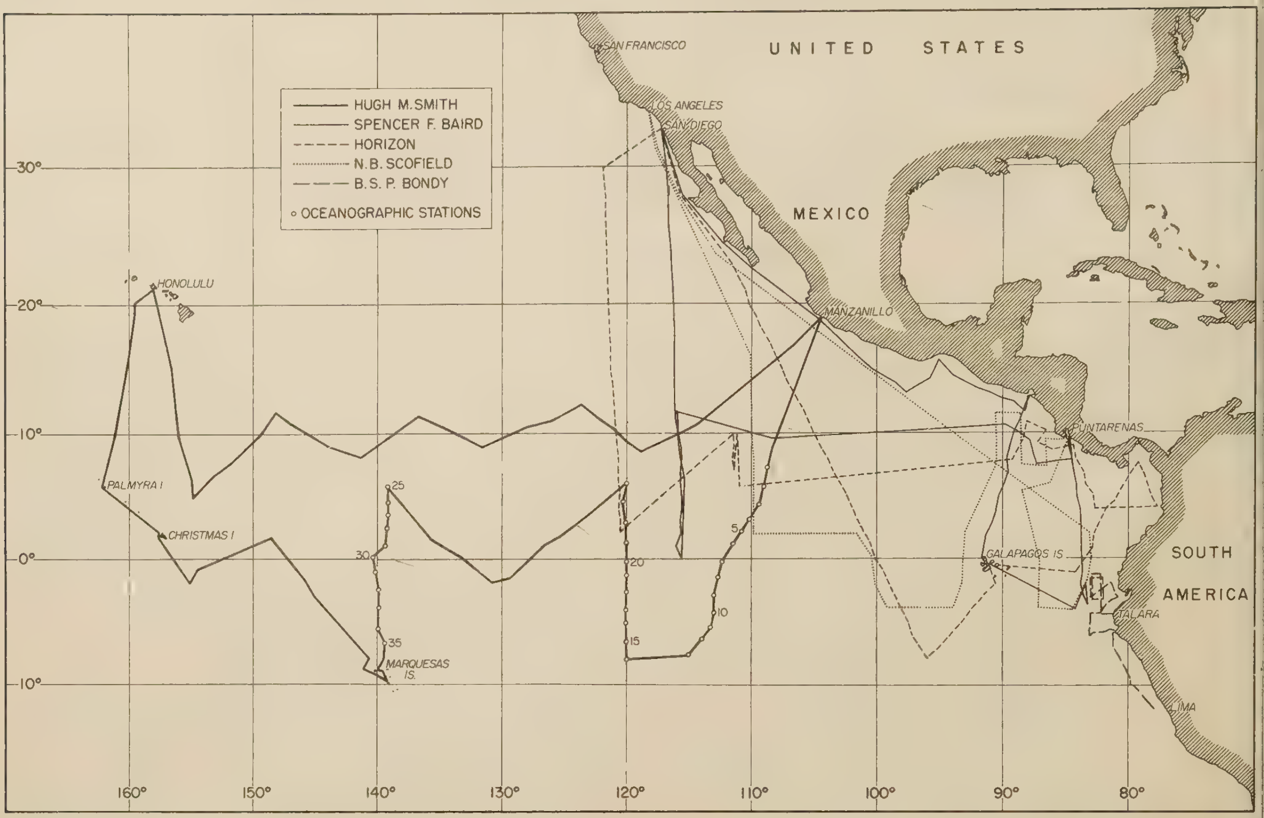
[1] Redesignated Bureau of Commercial Fisheries Biological Laboratory, Honolulu, effective Jan. 1, 1959.

NOTE.—Approved for publication, Nov. 21, 1958. Fishery Bulletin 168.


HUGH M. SMITH
SPENCER F. BAIRD
HORIZON
N. B. SCOFIELD
B. S. P. BONDY
OCEANOGRAPHIC STATIONS
SAN FRANCISCO
UNITED STATES
LOS ANGELES
SAN DIEGO
MEXICO
MANZANILLO
PUNTARENAS
GALAPAGOS IS.
SOUTH AMERICA
TALARA
LIMA
HONOLULU
PALMYRA I
CHRISTMAS I
MARQUESAS IS.
25
30
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15
5
10
30°
20°
10°
0°
10°
160°
150°
140°
130°
120°
110°
100°
90°
80°

FIGURE 1.—Track chart of vessels participating in expedition Eastropic. Positions of oceanographic stations shown only for *Hugh M. Smith.*

October 10, 1955. The northern edge of the Countercurrent was followed east to 120° W. During this eastbound leg of the cruise, bathythermograph (BT) lowerings were made at 2-hour intervals and surface samples were collected twice daily for inorganic phosphate and salinity determinations. The vessel then proceeded to Manzanillo, Mexico, for refueling and supplies.

The *Smith* departed Mexico on October 24, 1955, on a generally southwesterly course across the coastal currents, the Countercurrent, and to 8° S. latitude in the South Equatorial Current. The westward passage was planned in order to study the equatorial divergence and the associated oceanographic and biological events. A series of standard oceanographic casts to 1,200 meters was made at approximately 90-mile intervals, between 6° N. and 8° S. latitude near 110° W., along 120° W., and along 140° W. longitude. The northernmost station of the 110° W. leg was in the Countercurrent. The rest of the stations were in the westerly flowing South Equatorial Current. Bathythermograph lowerings were made at each station and at 2-hour intervals between stations. Surface phosphate and salinity samples were taken at frequent intervals.

The data resulting from the observations and collections taken by the *Smith* during expedition Eastropic have been published by King, Austin, and Doty (1957); those from the *Baird* and the *Horizon* by the University of California (1956). Both of these publications include tabulations of the observed data and a description of the sampling and analytical methods used aboard the vessels. The report of King et al. also includes oceanographic station curves, tabulations of the biological data and a description of the methods used in the shore-based processing and analyses.

The purpose of this paper is, primarily, to describe the oceanic circulation features and the associated distribution of variables as determined from the data collected by the *Smith*, particularly those features having significant influence on the distribution and abundance of the biota. Data from other participating vessels and those from previous surveys to the Eastern Central Pacific, both by POFI and other agencies, will be used as needed.

RESULTS OF OCEANOGRAPHIC OBSERVATIONS

We shall, in general, describe the results of the oceanographic program of the *Smith* in the following order: The general circulation, the vertical distribution of variables, their horizontal distribution, and finally, a discussion of the significance of the circulation features to the distribution and abundance of the biota. In each section we shall describe first the conditions in the Countercurrent, then those in the South Equatorial Current; the latter with particular attention to conditions along the Equator.

CIRCULATION FEATURES

As an introduction to the discussions of the observed vertical and horizontal distribution of the oceanographic properties, we shall first describe the general circulation features for the area and period of the *Smith* cruise. The direction of flow normal to the three oceanographic sections (henceforth referred to as 110° W., 120° W., and 140° W.) was determined by means of geostrophic calculations. Inferences as to direction in the region of the Countercurrent and elsewhere in the area where density data were lacking, were made from variations in the temperature-depth distribution. Information on variations in velocity was derived from changes in wire angles between successive Nansen-bottle casts. Frequent references will be made to the results of the GEK measurements made aboard the *Baird* and the *Horizon*.

The geopotential anomalies were computed, with pressure terms neglected, directly from the oceanographic station graphs (see King et al., 1957, fig. 9). The average values of thermosteric anomaly for depth intervals of 100 meters in the deeper layers and 10 meters in the thermocline and mixed layer, were multiplied by the pressure interval in decibars and then were summed upward from the 700-db. level. The 700-db. surface was used as the reference level since the bottom bottle on several stations was down less than 800 meters due to large wire angles.

In figure 2, the heights of the sea surface in dynamic centimeters (as calculated from the stations along 110°, 120°, and 140° W.) have been contoured relative to the 700-db. surface. The configurations of the isopleths for the geopotential anomaly between the three longitudes were drawn from consideration of the temperature-depth data. The inferred direction of flow is shown by the heavy arrows.

The station-to-station variation (meridional slope) of the 0/700-db. surface for each of the three sections is shown in figure 3. The slope, indicative of the speed of westerly flow, is steeper between the Equator and 5° N. on the 110° W. and 120° W. sections being, respectively, 0.28 and 0.42 dynamic meters in 570 km. This is to be compared with 0.07 dynamic meter over the same distance along 140° W. The surface velocities relative to the 700-db. level (as well as the velocities for the remainder of the *Smith* sections) are given in the following table. As the geostrophic approximation is not considered applicable near the Equator, relative velocities between 3° N. and 3° S. have not been calculated.

Latitude	140° W.		120° W.		110° W.	
	Speed (knot)	Direction	Speed (knot)	Direction	Speed (knot)	Direction
7° N–6° N	--------	--------	--------	--------	0.2	E
6° N–5° N	--------	--------	0.4	W	.4	W
5° N–4° N	0.1	W	2.3	W	.7	W
4° N–3° N	.2	W	1.8	W	.8	W
3° S–4° S	.6	W	.2	W	.4	E
4° S–5° S	1.0	W	.8	W	1.1	W
5° S–6° S	.3	W	.7	W	.5	E
6° S–7° S	--------	--------	.3	W	.6	W

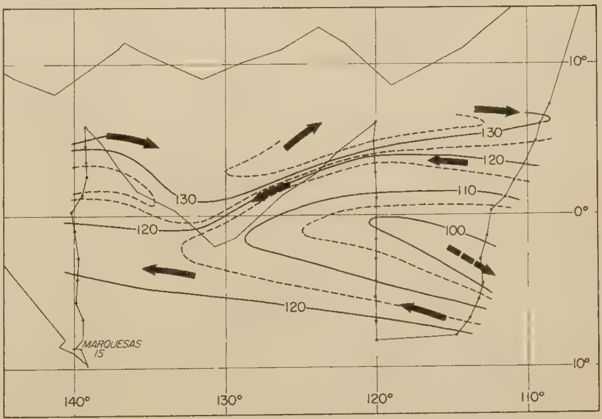

FIGURE 2.—Variations in the geopotential topography, 0/700-db. surface as calculated from Eastropic data. The arrows denote the direction of flow. (Contour interval, 5 dynamic centimeters.)

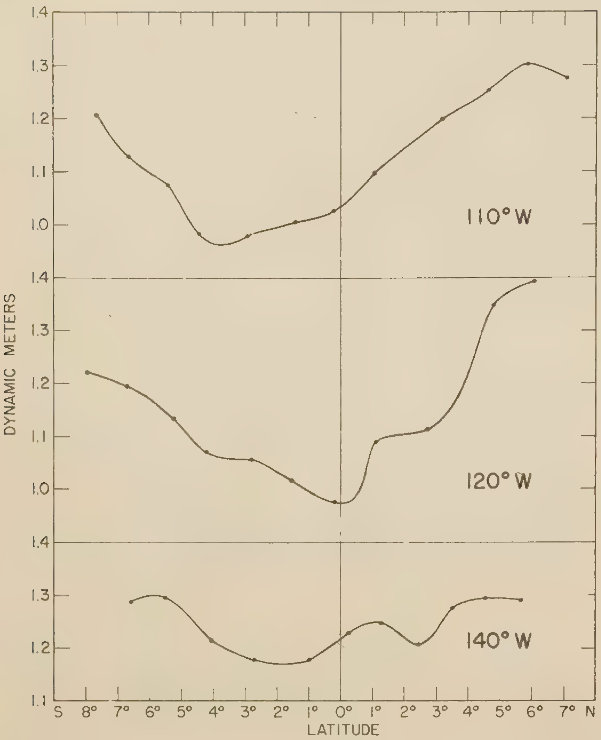

FIGURE 3.—Station-to-station variations in the geopotential topography (0/700-db. surface) for the *Hugh M. Smith*, 110° W., 120° W., and 140° W. sections.

Unfortunately, the *Smith* was not equipped to make direct measurements of velocities for these transects. Surface currents measured by the GEK aboard the *Horizon* (University of California, 1956), 5°09′ N. to 2°11′ N. latitude, near 120° W. longitude (October 11 and 12, 1955), varied between 0.86 knot (323° T.) at 2°48′ N. and 2.0 knots (324° T.) at 3°08′ N., the latter value being measured near a marked temperature discontinuity (front). The contours in the region of the front (fig. 2), also encountered by the *Smith* (near 4° N., 120° W.), are rather closely spaced reflecting the comparatively swift westerly flow measured by the *Horizon*. The *Baird*, near 115° W. longitude and between the same limits of latitude, observed velocities between 1.1 knots (063° T.) at 5°02′ N. and 5.7 knots (288° T.) at 0°43′ N. As can be seen from table 1, the calculated relative velocities for the *Smith*'s survey did not exceed 2.3 knots (3° N.–4° N. along 120° W.).

Referring to figure 3, the break in slope near the northern limit of the 110° W. section suggests the northernmost station was in the Countercurrent. The lack of a break in slope between the two northernmost stations of the 120° W. and 140° W. sections suggests these sections did not reach into the Countercurrent. In the southeastern portion of the survey area, the geostrophic considerations yield an easterly flow centered about 2° S. latitude (fig. 3, 110° W. section). The trough normally centered at or very near the Equator is, in this instance, positioned at 4° S. latitude.

Indirect evidence of the easterly flow in the surface waters, 1° S. to 4° S., is to be found in the wire-angle data for the Nansen bottle casts. Along the 110° W. section, the angles near to and north of the Equator (to 4°30′ N.) were large, 50° to 60° from the vertical. These large angles were the cumulative effects on the wire of the easterly winds on the vessel, the westerly surface flow and the decrease in velocities at the subsurface levels penetrated by the cast. Between 1° S. and 4° S., with 11- to 15-knot easterly winds, the angles fell to less than 10° (06° at 1°23′ S. and 03° at 2°54′ S.). The easterly surface flow exerted a “canceling effect” on the vessel and the wire angles thus were very small.

On both 110° W. and 120° W., there was an appreciable change in wire angle near the front, with smaller angles to the north of the front (10°) and larger angles to the south (50°). These differences in angle reflect the differences in velocity of the surface waters. The two stations on 120° W. nearest the front were station 22, approximately 90 miles to the south of the front, and station 23, approximately 30 miles to the north of the front. Referring to velocity measurements made aboard the *Horizon* (University of California, 1956), the speed of the surface flow decreased from near 4 knots in waters to the south of the front to 1 knot or less in those to the north. Considering that most of the Nansen bottles and wire were in deeper waters of low velocities, the comparatively swift surface currents south of the front would result in such large wire angles.

VERTICAL DISTRIBUTION OF PROPERTIES

Temperature

Temperature sections along selected longitudes (120° W. to 160° W.), each crossing the main features of the equatorial zonal circulation in the central Pacific, have previously been published in POFI oceanographic and biological reports (i.e., Cromwell 1954; Stroup 1954; Austin, 1954a and

1954b; and Murphy and Shomura, 1953). During Eastropic, no single leg of the *Smith's* track provided data for such a section. Therefore, in figure 4, two BT sections, one near 155° W. from 15° N. to 5° N. and one along 140° W. between 5° N. and 8° S. are used to illustrate the north-south temperature-depth distribution. The 60°, 70°, and 80° F. isotherms were drawn with the 72° and 74° F. isotherms included near the Equator.

From north to south (right to left in fig. 4, A) in the North Equatorial Current, the isotherms slope upward, reaching a minimum depth at the northern boundary of the Countercurrent, then slope downward to the southern boundary of the Countercurrent. This interpretation of the current boundaries is based on the assumption of geostrophic flow. In the next section (fig. 4, B), 140° W., 4° N. to 4° S., both the upward trend of the isotherms toward the Equator and their deepening south of the Equator, compatible with westerly flow, are discernible. Various mixing processes at or near the Equator resulted in the "irregularities" which mask the ridge expected from the distribution of mass when a westerly flow is centered about the Equator.

The mixing of the cooler subsurface waters with those at the surface near the Equator is reflected in the configuration of the 74° F. isotherm, which intersects the surface to the north and to the south of the Equator. A trough in the isotherms centered beneath the Equator is suggested in figure 4, but it is not as evident as generally found in meridional sections crossing the Equator in the central Pacific (Austin 1954b; Wooster and Cromwell, 1958).

The 60° and 70° F. isotherms at the southern limit of the 155° W. section (fig. 4, A) are about 50 meters deeper than those at the northern limit of the 140° W. section. This difference results from the rapid east-west deepening of the thermocline between 125° W. and 160° W. longitude.

To illustrate this deepening, temperature-depth data from BT's taken at eight positions along the Equator, 112° W. to 156° W. longitude, have been contoured in figure 5. Near 155° W., the top of the thermocline is at 150 meters, decreasing in depth to 50 meters near 125° W., then deepening slightly toward the eastern end of the section.

Other features in the temperature-depth distribution of the three meridional sections warrant attention. Of the sections that crossed the Equator (see fig. 1), three were made along courses nearly normal to the Equator. The temperature-depth profile for each of these sections is shown in figure 6, A (110° W.), 6, B (120° W.), and 6, C (140° W.). In all three, the well-developed two-layer system, characteristic of tropical waters, is evident. The principal variation among the three sections is in the depth of the thermocline.

Along the 110° W. section (fig. 6, A), there is a gradual decrease in depth of the thermocline from 5° N. latitude south across the Equator to 4° S. latitude. This suggests that between 0° and 4° S. there is a reversal in flow with the surface waters directed to the east, becoming westerly again south of 4° S. Two centers of cold water at

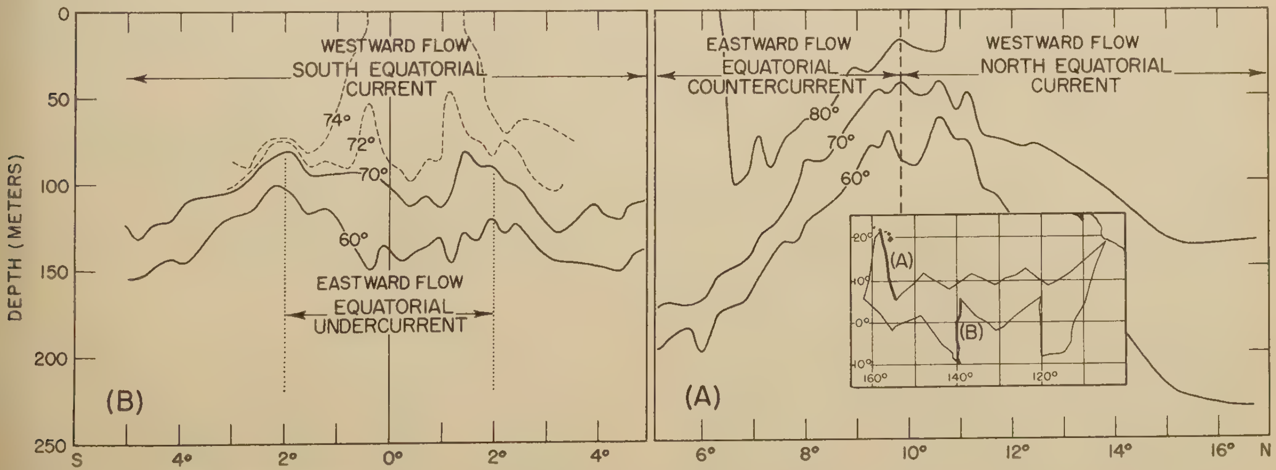

FIGURE 4.—Vertical temperature (°F) section from Eastropic BT records; composite of such records along 140° W. and 155° W. longitude.

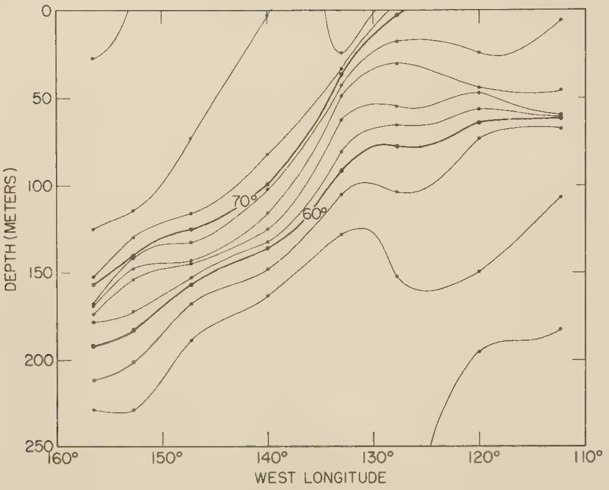

FIGURE 5.—Vertical temperature (° F.) distribution along the Equator illustrating the east-west slope of the thermocline.

the surface are shown. One center near the Equator and similar to that described for the 140° W. section (fig. 4) results from the effects of the wind-induced divergence and upwelling. At the second, near 4° S., the shallow thermocline, coupled with mixing by the wind and by the turbulence at the interface of the opposing easterly and westerly surface currents, results in cooler water at the surface.

The second meridional section, that along 120° W., is shown in figure 6, B. Within the comparatively short span of the section, 6° N. to 8° S., the thermocline approximates a dome with its center positioned at the Equator. Near the northern end of the section, the isotherms show a reversal in slope, decreasing in depth to either side. This trough undoubtedly approximates the position of the southern boundary of the Countercurrent. The domed configuration over the rest of the section reflects the flow of the westerly South Equatorial Current.

Near 4° N. latitude, 120° W. longitude, the isotherms (70° to 76° F.) abruptly descend from the surface. It was near here that the *Smith* crossed a marked front such as that encountered during a previous cruise to this area (Cromwell and Reid, 1956). A temperature-depth section drawn from BT data taken at and within a few miles either side of the front is shown in figure 7. One BT (No. 447), taken with vessel underway at 2 knots, was sufficiently close to the front so that the "up" and "down" traces in the first 2 meters differed by 3° F., and could be used as reference to locate the position of the other BT records relative to the front. Following Cromwell and Reid (1956, figs. 3 and 4), the water which were "nearly isothermal" have been shade in figure 7.

The Scripps vessel, the *Horizon*, observed a similar feature 1 month later near 3° N. latitude 120° W. longitude (Knauss 1957). Knauss interprets the circulation at the front as "cold wate overrunning the less dense warm water and the plunging downward." He describes the feature a a "cold front" with the cold water to the sout moving at right angles to the front at speeds i excess of 2 knots.

Along the 140° W. section (fig. 6, C), the decrease in temperature per unit of depth throug the thermocline is less than in the previous tw sections (110° W. and 120° W.), and the thermocline, 4° N. to 4° S., is 50–75 meters deeper. Th influence of the Equatorial Undercurrent on th vertical temperature distribution is suggested between 2° N. and 2° S. latitude. With westerl surface flow along the Equator, a ridge centere near the Equator is expected. North and south o 2° N. and 2° S., respectively, the thermocline show an upward trend toward the Equator. Betwee these two latitudes is a trough; i.e., warmer water at greater depths. This trough may be interprete as the result of advection of the warmer water from the west into the lower part of the surfac layer and to an unknown depth into the thermocline (Fofonoff and Montgomery, 1955). A similar situation, vertical spreading of the isotherms may be seen (2° N. to 2° S.) on the 120° W. sectio (fig. 6, B) and to a lesser degree on the 110° W section (fig. 6, A). On the latter section, however is a southerly displacement of the trough, undoubtedly related to the easterly surface flow south o the Equator (1° S. to 4° S.). Further details o the 140° W. vertical temperature section were discussed in connection with figure 4.

Salinity

The most prominent feature in the subsurfac distribution of this variable is the tongue of hig salinity water south of the Equator at a dept of about 150 meters (fig. 8). In comparing th salinities in this feature on the three sections, ther

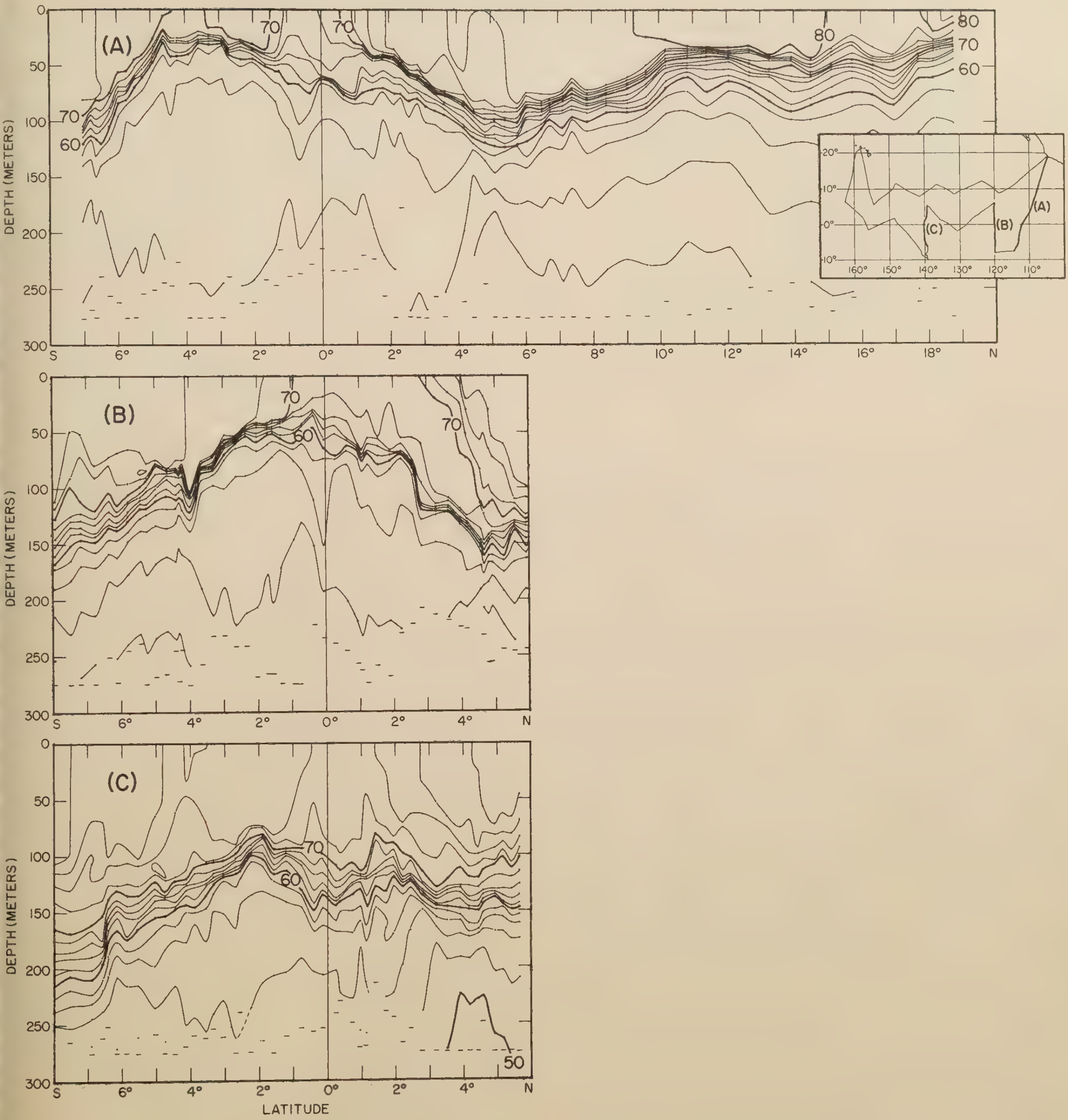

FIGURE 6.—Bathythermograph temperature-depth sections 110° W. longitude (A); 120° W. longitude (B), and 140° W. longitude (C). Contour interval 2° F. (from King et al., 1957).

is a progressive increase, east to west, from 35.30 °/₀₀ to 35.80 °/₀₀ to a maximum of 36.13 °/₀₀. From east to west there is an increasingly apparent northward extension of the tongue.

The source of these higher salinity waters at an intermediate level is a Southern Hemisphere salinity maximum in the surface waters positioned near 20° S., extending east to west between approximately 100° W. and 140° W. (Fleming et al., 1945, fig. 222). In this region of descending flow of air in the atmosphere above the ocean and associated evaporation from the sea surface, more saline waters are formed and sink, moving northwesterly then westerly at subsurface levels. The

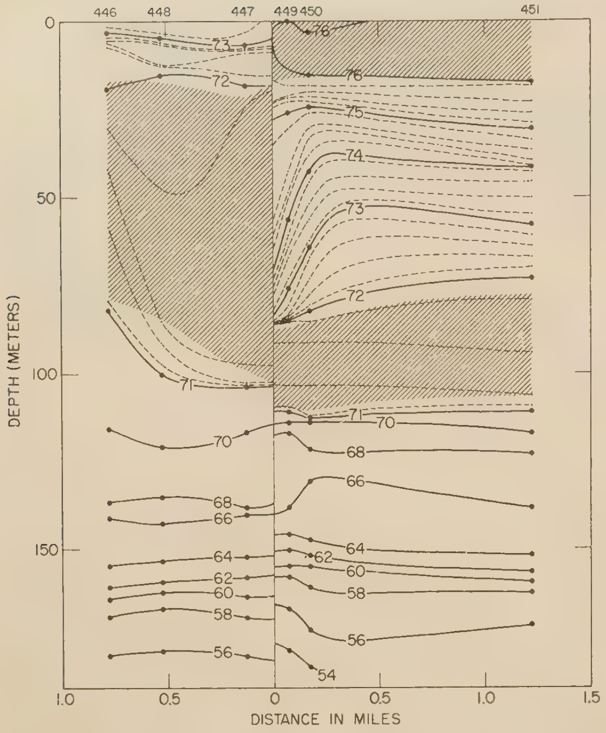

Figure 7.—Vertical distribution of temperature (° F.) across the front observed by the *Smith* near 4° N. latitude, 120° W. longitude.

relation between the position of the surface salinity maximum and the subsurface trajectory is reflected in the variations in the feature on the three longitudes (fig. 8); i.e., its northern extent ends abruptly near the Equator in the central and east-central Pacific. This was shown in previous POFI sections by Cromwell (1954), Austin (1954a, 1954b), Stroup (1954), Montgomery (1954), and by Fleming et al. (1945, figs. 119 and 143). Austin (1954b, fig. 21) has shown by the temperature-salinity characteristics that this abrupt termination of the salinity maximum at the Equator in the eastern Pacific is associated with the vertical mixing processes accompanying upwelling. In contrast, in the western Pacific the maximum penetrates into the Northern Hemisphere, reaching at least 5° N. (Mao and Yoshida, 1955). Austin and Rinkel (in press) suggest that this is evidence for less-intensive upwelling in the western Pacific.

Comparison of the temperature/salinity (T/S) characteristics for the Eastropic stations along 110° and 120° W. also reveals the longitudinal variation in the subsurface salinity maximum and the rather abrupt change near the Equato Along 110° W. (fig. 9, A), the T/S curves sout of the Equator all show a rapid subsurface decrease in temperature with small change in salinity. Similar curves for the stations along 120° W (fig. 9, B) show a configuration for those station south of the Equator which is attributable to th subsurface maximum. On the T/S curve for th first station north of the Equator (station No. 21) 1°06′ N., 120° W., the Southern Hemisphere maximum is no longer in evidence.

Returning to figure 8, we note that the water in the surface layer near the northern limits o the three sections, particularly those along 110 W. and 120° W., are characterized by low salinities. Along 110° W., the salinities in the surfac layer are below 34.00 $^{\circ}/_{\circ\circ}$ (a minimum of 33.49 $^{\circ}/_{\circ}$ at the northern two stations (07°06′ N. and 05°52 N.). Westward along similar latitudes, there i a gradual increase to 34.47 $^{\circ}/_{\circ\circ}$ on the 120° W. se tion and 34.72 $^{\circ}/_{\circ\circ}$ on 140° W. These low saliniti are attributable to dilution by rainfall and influence of waters moving in from the east an northeast. As shown by Schott (1935), a ridge o mean maximum rainfall is centered along 10° N becoming increasingly prominent to the east an reaching a maximum in the Gulf of Panama East of the *Smith*'s survey area, as revealed b the *Carnegie* data (Fleming et al., 1945, fig. 222 and by data taken aboard the Scripps Institutio of Oceanography vessels during Eastropic (University of California, 1956), the salinities in th surface waters progressively decrease, reachin minimal values of 29.50 $^{\circ}/_{\circ\circ}$ to 30.00 $^{\circ}/_{\circ\circ}$ in th Gulf of Panama (3°–6° N. latitude).

In the deeper waters sampled during expeditio Eastropic, at 500–1,000 meters, the salinities wer those characteristic of the Antarctic intermedia waters with the axis of the lowest values risin toward the north on each section (King et a 1957, figs. 11, 16, and 21).

Density

The vertical distribution of density along eac of the three sections, expressed as thermoster anomaly in centiliters per ton (following Montgomery and Wooster, 1954), is shown in figure 1 The most striking feature on each of the three se tions is the rapid increase in density with dept (which we shall refer to as the stable layer

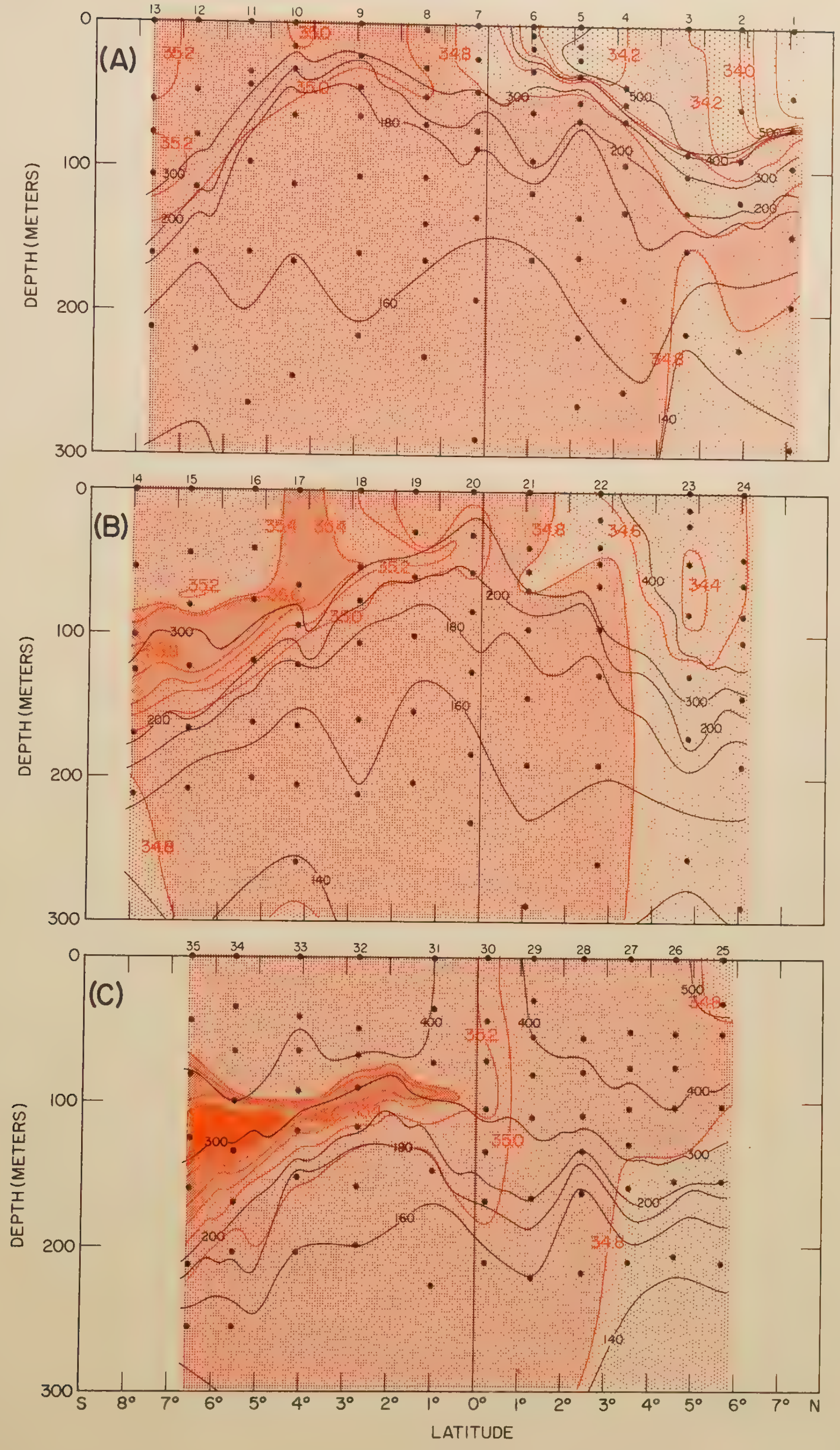

FIGURE 8.—Vertical distribution of salinity (°/₀₀) along 110° W. (A), 120° W. (B), and 140° W. (C). Contour interval 0.2 °/₀₀ (from King et al., 1957). Density isopleths in black (in centiliters per ton). Depths of observations are shown by dots; station numbers are given along the top of each panel.

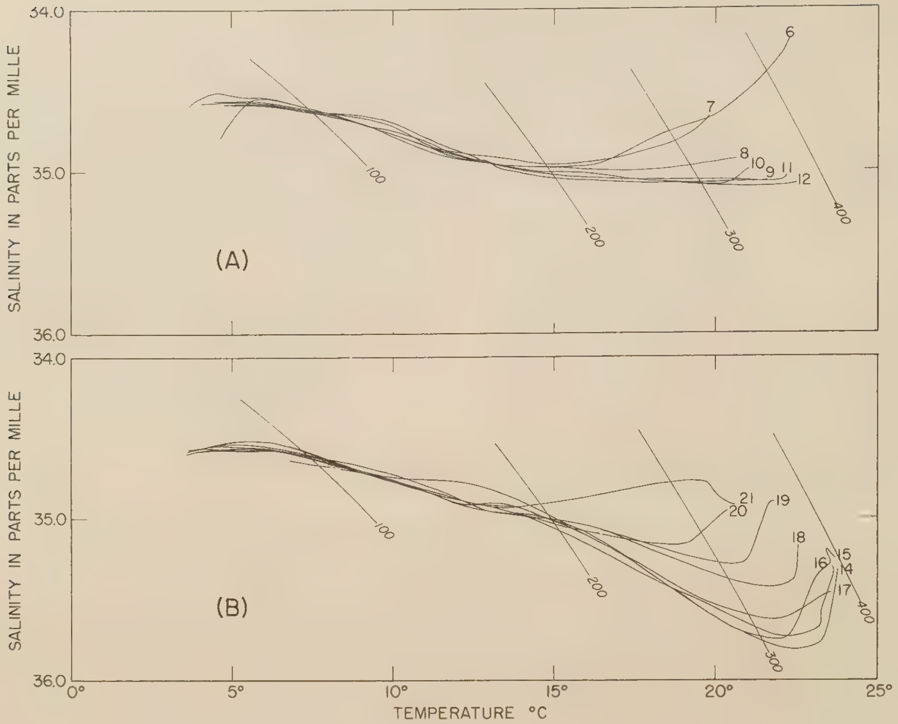

FIGURE 9.—Temperature (° C.)-salinity (°/₀₀) curves at selected stations, Southern Hemisphere along 110° W. (A), 120° W. (B). Density (oblique lines) in centiliters per ton.

through the thermocline. Although variations in salinity, as well as temperature, affect the vertical distribution of density of sea water, in tropical waters salinity usually plays a minor role. To illustrate: from east to west (particularly between the 120° W. and the 140° W. sections) there is a general increase in depth of both the thermocline and the stable layer. There is a trough in each at the southern boundary of the Countercurrent and a marked ridge near the Equator on 140° and 120° W., and near 4° S. on 110° W. The change in temperature and density across the front is reflected in the "bunching" of the density isopleths at their intersection with the surface near 4° N. on 120° W. and 1° N. on 110° W.

Oxygen

The vertical distribution of oxygen is shown in figure 11. Selected isopleths for δ_t are shown on each section. On the four longitudes, the oxygen content in the surface layers, surface to the top of the thermocline, was uniformly high, 4.0 to 5.5 ml./L., decreasing through the thermocline to the oxygen minimum, then increasing to maximum depths sampled. Near 100° W. and 110° W., the minimum with values of less than 0.5 ml./L. was continuous from the Southern to the Northern Hemisphere. Along the 120° W. and 140° W. sections, values less than 0.5 ml./L. were observed only in the Southern Hemisphere. On each section a narrow, vertical tongue of water with higher oxygen content was centered beneath the surface waters at the Equator.

The low oxygen values in the minimum south of the Equator (300–500 meters) are in waters which have moved westerly from the coast of Peru and, at least in part, result from the consumption of oxygen at subsurface depths by decomposition of the organic material which was in these waters when they departed from the surface and of the organic detritus sinking from the euphotic zone.

North of the Equator in the eastern Pacific is a large subsurface body of water within which the oxygen content is low (0.1 ml./L. or less). As described by Sverdrup et al. (1942, p. 729), this body of water is found off the American coast between 28° N. and the Equator, extending to the west as far as 140° W. More recent data (Cromwell 1951) bring this westward extension to at least 172° W. The lowest oxygen concentrations,

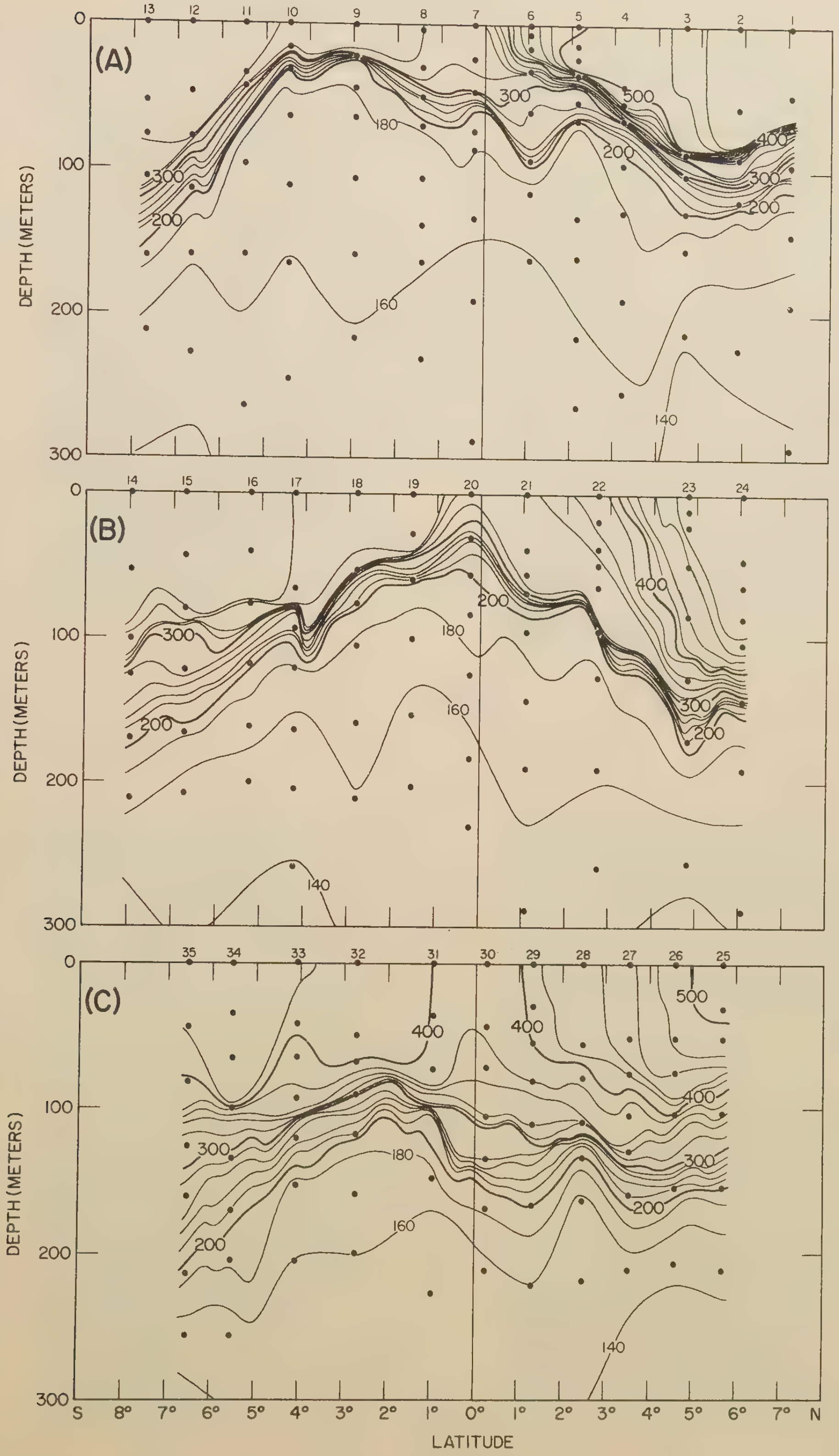

FIGURE 10.—Vertical distribution of density expressed as thermosteric anomaly along 110° W. (A), 120° W. (B), and 140° W. (C). Contour interval 20 centiliters per ton (from King et al., 1957). Depths of observations are shown by solid dots; station numbers are given along the top of each panel.

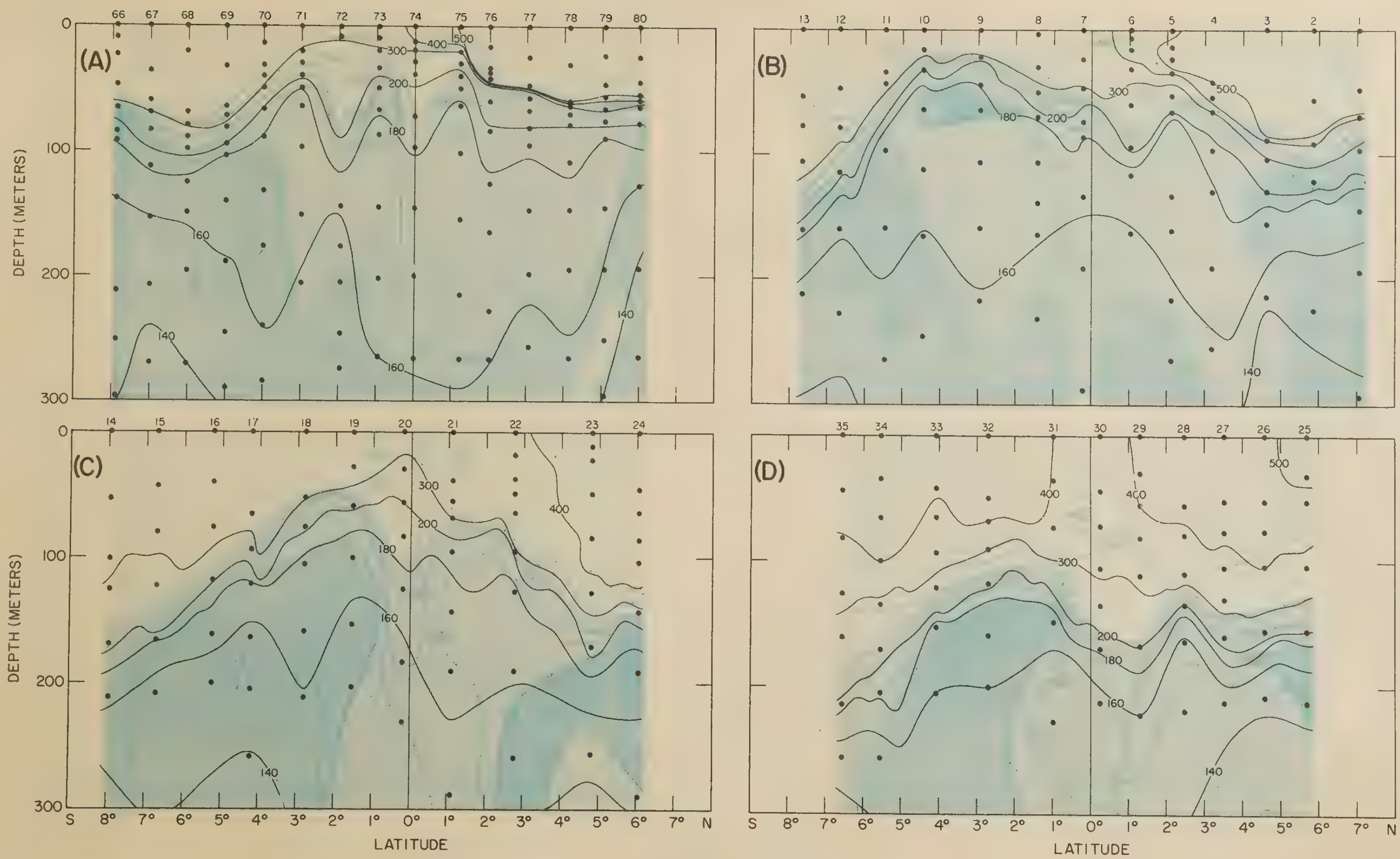

FIGURE 11.—Vertical distribution of oxygen expressed in milliliters per liter (ml./L.) along sections near 100° W. (A), 110° W. (B), 120° W. (C), and 140° W. (D). Contour interval 0.5 ml./L. (data for A from University of California, 1956; B, C, and D modified from King et al., 1957). Depths of observations are shown by dots; station numbers are given along the top of each panel.

without separating the double minima, have been contoured in figure 12. Values equal to or below 0.1 ml./L. have been shaded. The values in the minimum near the Equator are somewhat higher than those to the north or to the south.

Phosphate

The Automatic Servo-Operated Photometer used for the determination of inorganic phosphate broke down at station 8 along the 110° W. leg. Subsequently, samples were frozen from selected depths at the remainder of the stations along this leg, and at less frequent depth intervals (surface to 200 m.) along 120° W. The meridional sections resulting from these data are shown in figure 13.

Along 110° W., the phosphate concentrations in the mixed layer were low (0.4 µg. at./L. or less) between the northern limit of the section (7° N.) and about 2° N. The values progressively increased to a maximum of slightly more than 1.0 µg. at./L. at about 3° S., then decreased to less than 1.0 from 5° S. to the southern limit of the section (8° S.). Values in the mixed layer were also low (0.4 µg. at./L. or less) at the northern stations of the 120° W. section, but increased suddenly (0.4 to 1.0 µg. at./L.) upon crossing the front near 4° N. The highest values in the surface waters were near the Equator (1.2 µg. at./L.), decreasing to less than 1.0 µg. at./L. near 1° S. and remaining less than this value to 8° S.

Comparison of the phosphate concentrations in the mixed layer of the two sections reveals the association of this nonconservative property with the previously discussed vertical distribution of density (the thermocline) and zonal flow. In the northern portions of the sections, the low phosphate concentrations are in the impoverished waters of the Countercurrent. Near the Equator on 110° W., some enrichment results from upwelling, but the highest values on this section, near 4° N., result from the very shallow thermocline and wind "plowing" (Sverdrup 1952) into the deeper, nutrient-rich waters. Near the Equator on 120° W., the surface enrichment probably results primarily from upwelling. The northern transport of these waters is reflected in the higher phosphate values, from the Equator north to the latitude of the front.

HORIZONTAL DISTRIBUTION OF PROPERTIES

Although this section will deal primarily with the surface distribution of temperature, salinity, and phosphate, we shall, as necessary, include concurrent consideration of the vertical distribution of the property in question. The direction of the flow, as determined by geostrophic calculations (see fig. 2) has been reproduced on the charts.

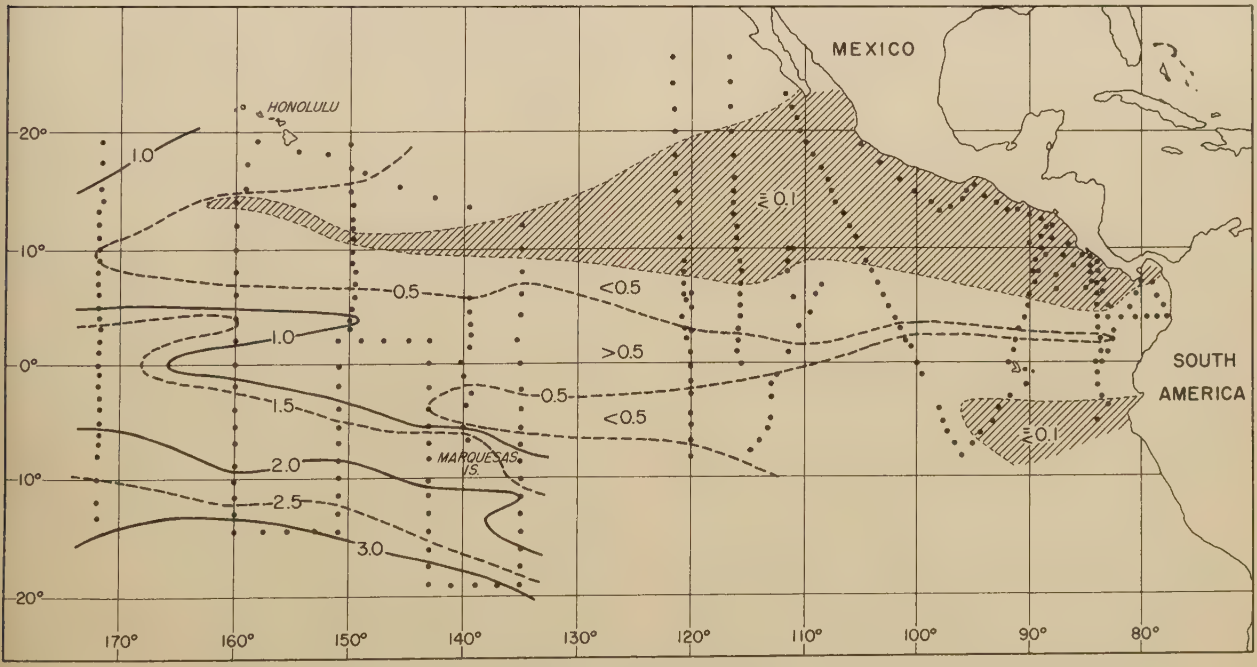

FIGURE 12.—Concentrations in the oxygen minimum. (Data from POFI and Scripps cruises.)

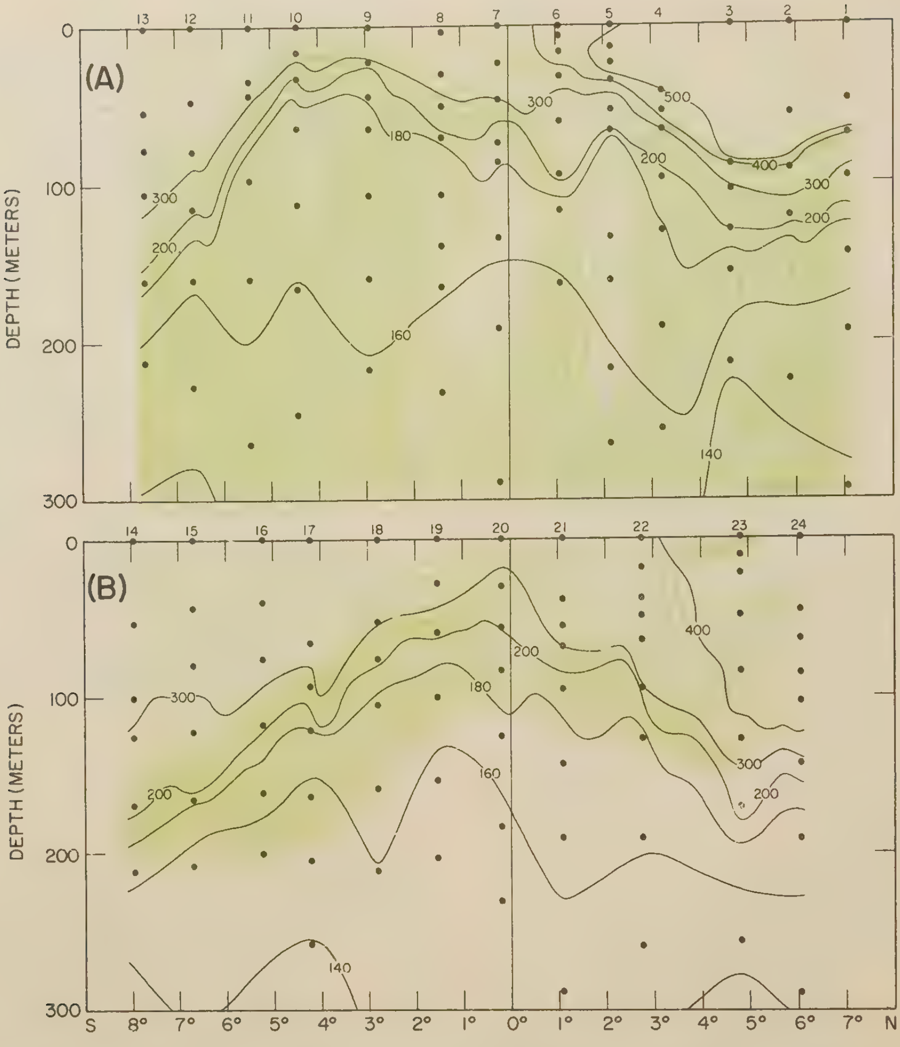

FIGURE 13.—Vertical distribution of phosphate expressed in microgram-atoms per liter (µg. at./L.) along sections near 110° W. (A) and 120° W. (B). Contour interval 0.2 µg. at./L. (from King et al., 1957). Depths of observations are shown by dots; station numbers are given along the top of each panel.

Surface Temperature

The surface temperatures, as measured in the bucket samples taken at each BT lowering (generally at 2-hour intervals, 15 to 20 miles apart) are shown by the black contours in figure 14. Mean surface temperature distribution for the month of November, as published in an atlas prepared by the British Air Ministry (1950), is shown by the red contours.

In the Countercurrent (5° N. to 10° N. latitude) there is general agreement between the Eastropic surface temperatures and the mean. Over most of the area the 80° F. isotherms in each case straddle the somewhat warmer waters in the center of the current, but swing northerly from the latitude of the axis in the eastern part of the survey area. This northerly shift in position of the isotherms reflects the influence of the warmer waters moving to the west away from the coast of Central America. A similar configuration of the surface isotherms is evident in the report by Jerlov (1956, fig. 3) describing the results of the Swedish *Albatross* expedition to the same area and during the same months (October–November 1948).

The distribution of surface temperatures (also salinity and phosphate) suggests that there was a southerly bulge in the Countercurrent centered

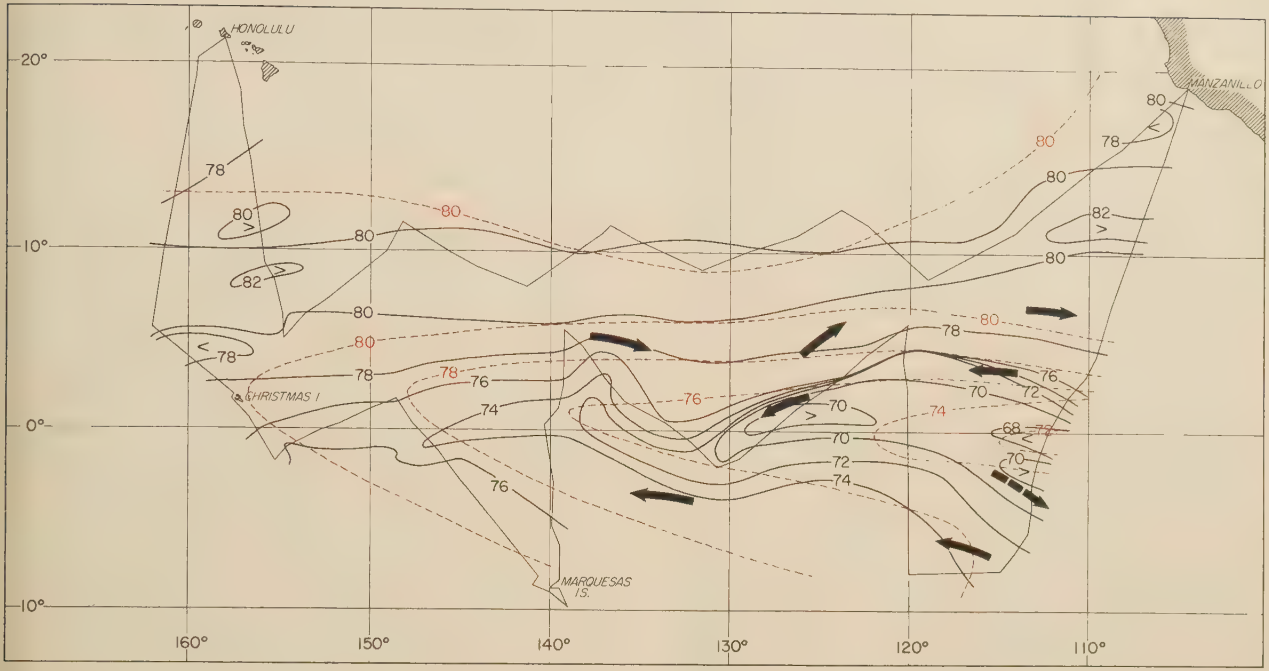

FIGURE 14.—Surface temperature (° F.) distribution from temperatures of bucket samples taken at position of BT lowerings in black; mean temperatures from British Air Ministry Atlas (1950) in red. The arrows denote current direction as determined from geostrophic calculations.

near 132° W. longitude. Although this feature appears to be real, there is the possibility that it is an artifact resulting from the V-shape of the vessel track in this area. There is an acceptable comparability, however, in the shape of the contours defining the bulge among all the surface variables measured. Similar variations were reported by Cromwell (1956, p. 29) during expedition Eastropic.

The cooler surface temperatures in the South Equatorial Current, particularly along the Equator, are strikingly evident. In fact, those observed near the Equator during the period of Eastropic were from 2° to 4° F. cooler than the mean. At any point along the Equator, these cooler waters reflect both the mixing of the deeper waters with those at the surface and, in varying degrees, advection from the east. The mixing involves at least two separate physical processes, one related to the divergence of the surface waters under the influence of winds with an easterly component, the other, mixing by the wind which is more effective in the east because of the west-to-east shoaling of the thermocline. At present, quantitative estimates of the relative roles of each of these two processes are not available.

The oceanic front described in earlier sections was evident near 4° N. latitude on 120° W. longitude, across which there was an abrupt change in surface temperature of nearly 4° F. (fig. 14). This circulation feature was discernible in varying degrees near 4° N., 135° W. and 2° N., 112° W. That it may be a semipermanent feature in this region of the Pacific is evidenced by the fact that during expedition Eastropic the Scripps vessel, the *Horizon*, observed it 1 month later than did the *Smith* (Knauss 1957), and a similar feature was previously detected by the *Smith* near 1° N., 120° W. on October 27, 1952 (Cromwell and Reid, 1956). However, a front was not detected by the *Albatross* during October–November 1947 when she crossed the Equator at 137° W. (Jerlov 1956, p. 150), nor by the *Baird* which was working during expedition Eastropic only 300 miles to the east of the *Horizon* (Knauss 1957).

Depth of Thermocline

From the preceding discussion of the distribution of temperature, it is evident that there was considerable variation in depth of the thermocline throughout the area surveyed by the *Smith*. The thermocline depths, as read from the BT slides, have been plotted and contoured in figure 15.

On and near the Equator an objective determination of the thermocline depth is generally difficult since in this region there often is either more than one inflection of the curve or a continuous negative gradient from the surface to the maximum depth of the BT trace (fig. 16). In both figures 15 and 16 this region has been indicated by shading, and the contours in figure 15 have been terminated at their points of intersection with the northern and southern boundaries of this region. This was done because there is a question as to whether or not the two well-defined thermoclines, one south of the Equator and one to the north, are the result of the same physical processes.

Certain inferences to the circulation features may be drawn from the spacing and configuration of the contours in figure 15. The northern boundary of the Countercurrent was coincident with the ridge near 10° N. (<100 ft.) and the southern boundary was centered along the trough in the thermocline depth near 5° N. latitude. In the southeastern portion of the area, a second ridge is evident at about 4° S. latitude. This reflects the distribution of mass associated with easterly flow there (see the results of the geostrophic calculations in fig. 3).

Surface Salinity

The lowest surface salinity values (fig. 17) were measured along the northern boundary of the Countercurrent, with the minimal value (33.6 °/₀₀) being near 10° N., 128° W. This distribution reflects the extension of low salinity water westward from the coast of Central America and is also coincident with the zonal band of high rainfall located near 10° N. (Schott 1935, plate XIX).

As the *Smith* proceeded south across the Countercurrent and into the South Equatorial Current, surface salinity generally increased, reaching the maximum observed values at the southern extremities of the *Smith's* tracks. Somewhat farther south (near 20° S. latitude) was the southeastern Pacific salinity maximum, with surface values of 36.00 °/₀₀ or greater (Sverdrup et al., 1942, chart VI).

Near the front, the configuration of the isohalines showed an abrupt discontinuity in salinity, with higher salinity water, reaching 34.9 °/₀₀, on the northern side of the front and surface waters with lower salinity, 34.2 to 34.4 °/₀₀, to the south

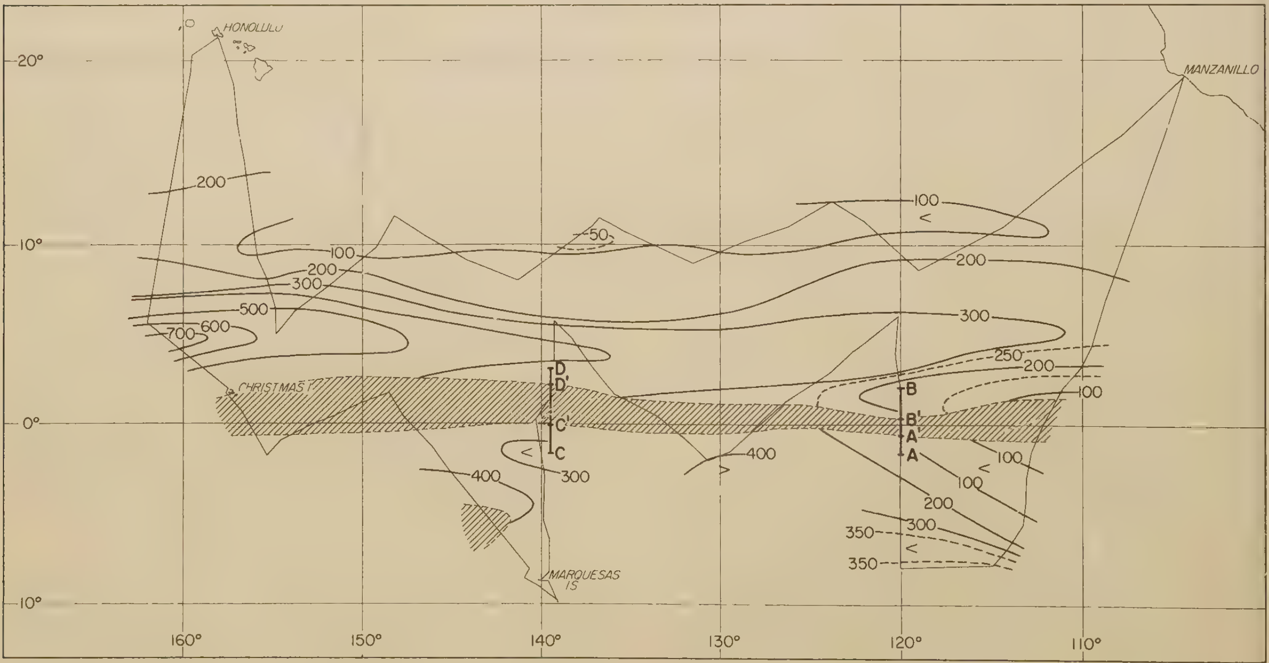

FIGURE 15.—Depth of the thermocline as determined from the BT data. (For explanation of shaded section, see text above.)

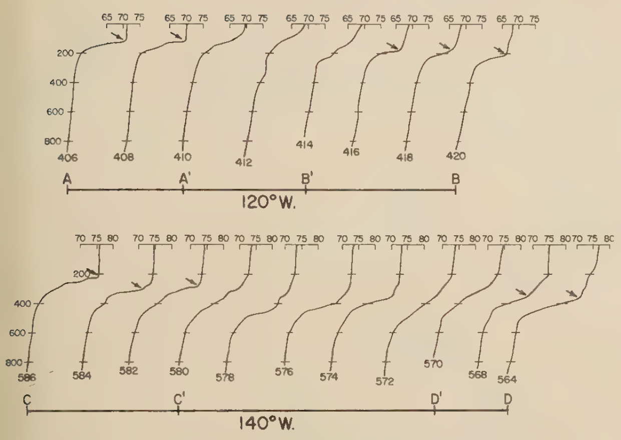

FIGURE 16.—Temperature–depth traces for selected BT records between A–B and C–D, figure 15. Arrows denote the thermocline depth as plotted in figure 15; the BT number is noted at bottom of each trace.

of the frontal line. Knauss (1957, table 1) reported a somewhat dissimilar situation, with higher salinities in the cooler surface waters to the south of the front (34.49 to 34.54) and a lower salinity to the north (34.46).

Phosphate

The concentration of inorganic phosphate (PO_4–P) in the surface waters was determined at frequent intervals during the cruise. The results are shown in figure 18.

In the surface waters of the Countercurrent, the supply of this nutrient was relatively low. These are "old" waters in the classification of Steemann Nielsen (1954)—they have been at the surface for a considerable period of time as they have moved from the west in a current in which stabilization is markedly developed and vertical mixing is limited. East of 140° W., the surface values are below 0.5 µg. at./L., a level regarded by Ketchum (1939) as limiting photosynthesis. These relatively low values (0.3 to 0.4 µg. at./L.) in the surface waters represent the balance in the mixed layer among utilization by the phytoplankton, biological regenerative processes, and vertical diffusion.

In the South Equatorial Current, the phosphate concentrations generally peak at or near the Equator with values of 1.0 µg. at./L. or more. The concentrations decrease rapidly to the north and south, and more gradually east to west. Along 110° W. the highest concentration of phosphate was south of the Equator, peaking at about 4° S. This results from the proximity of the thermocline to the surface and wind mixing discussed in the section on surface temperature. The con-

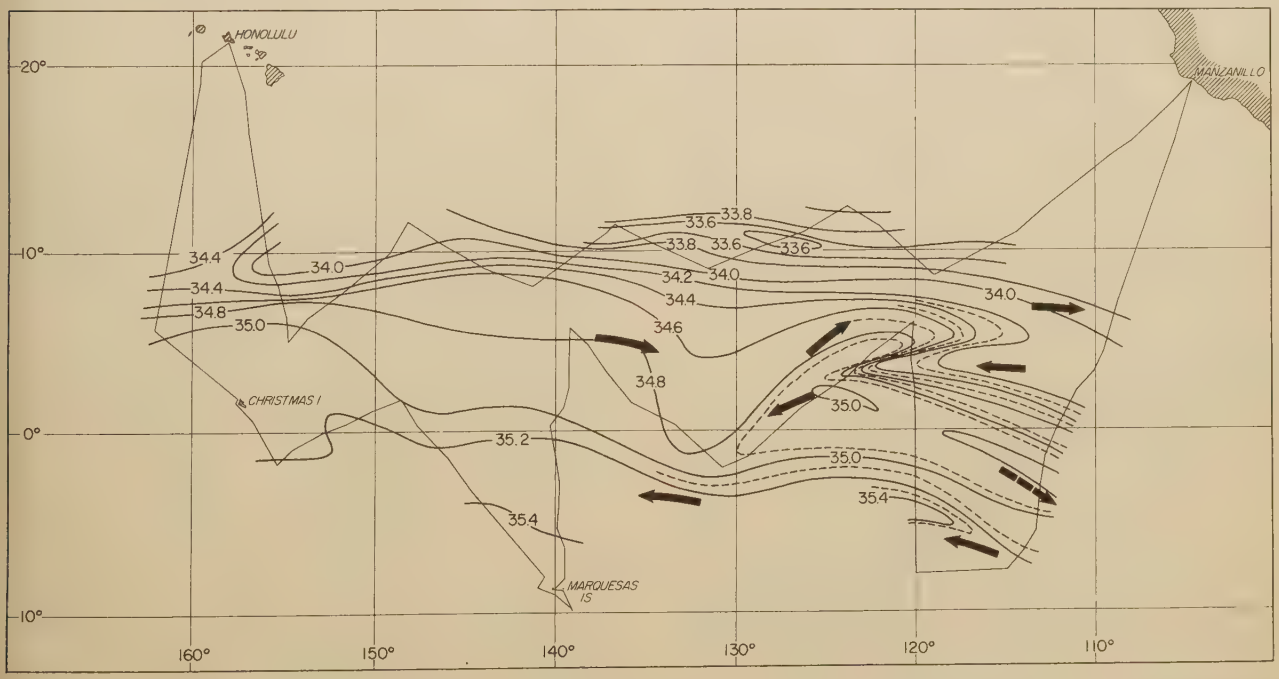

FIGURE 17.—Surface salinity (°/₀₀) distribution. The arrows denote current direction as determined from geostrophic calculations.

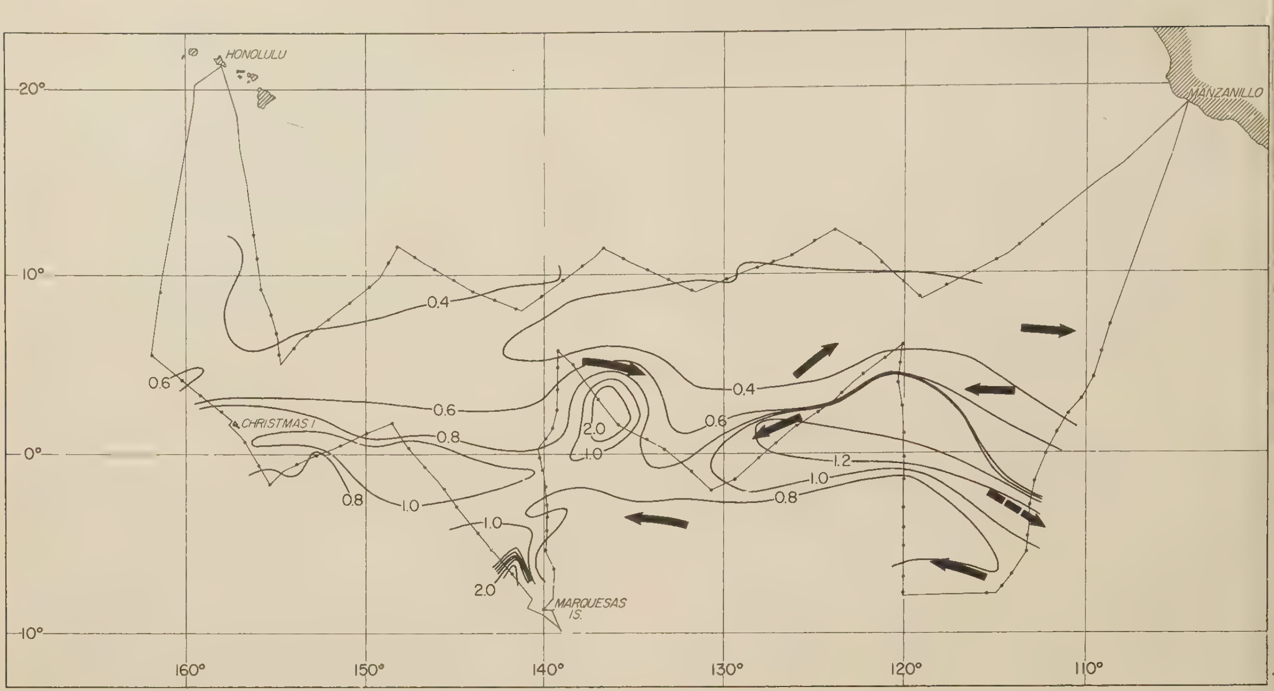

FIGURE 18.—Distribution of inorganic phosphate (μg. at./L.) in surface waters. Surface samples were taken at the position of the oceanographic stations and at the time of the BT lowerings. The positions at which the samples were taken are indicated. The arrows denote current direction as determined from geostrophic calculations.

centrations of 1.0 to 2.0 μg. at./L. near 137° W. and 3° N. are difficult to explain. Unfortunately, there are no subsurface phosphates available for analysis of vertical transport, and no indications of such in the temperature fields. There are no apparent indications of analytical error. More than one sample is involved and the high values are consistent among these samples. One explanation is that these waters reached the surface near the Equator and moved to the position where sampled from the *Smith*. A similar situation was described by Sette et al. (1954) near 3° N. and 165° W. The high value near the Marquesas, 7° S., 142° W., may have resulted from some as yet undetermined circulation feature(s) associated with the islands. Similar concentrations in this area were observed during the recent participation of the *Smith* in Equapac (Austin 1957).

DISCUSSION OF RESULTS

Eastropic was a combined physical and biological study of the eastern central equatorial Pacific. The results of POFI's oceanographic observations have been described in the preceding sections of this report. The results of the biological sampling program will be considered in relation to these environmental features. Before this can be done we must consider the question, "How typical were the environmental factors?" It appears that the oceanographic conditions were somewhat atypical.

The surface temperatures along the Equator (fig. 14) were 2°–4° F. cooler than normal; those in the Countercurrent showed little variation from normal. Waters were also cooler than normal at four stations in the eastern Pacific (fig. 19) one each off California, Panama, Peru, and Christmas Island (Line Islands group). Rodewald (1956) demonstrates that these below-normal surface temperatures were typical for the entire eastern Pacific during 1955, particularly the latter half of the year. North to south, he reports anomalies in 1955 of −0.9° F. for Alaskan waters, −1.7° F. for Washington and Oregon, −1.2° F. for California, and −0.6° F. for Chile and Peru. These temperatures and the cooler water observed by the *Smith* in the South Equatorial Current may be considered to be "eastern Pacific temperatures," while the normal temperatures in the easterly flowing Countercurrent more or less reflect conditions farther to the west. In the western Pacific near the Philippines, the anomaly in 1955 was +0.2° F., exceeding +1° F. for August through November.

The comparatively high measured and calculated speeds of surface flow in the South Equatorial Current, as well as the cooler than normal waters at the surface in the eastern Pacific, suggest that the circulation during expedition Eastropic was more vigorous than normally observed. If such was the case, this should be reflected in the distribution of mass.

Montgomery and Palmén (1940), using data from one station near 99°07′ W. and the mean of three near 135° E., calculated the mean slope of the sea surface (0/400 db. reference level) to be 4.0×10^{-8}, with a difference in level of 0.7 dynamic meter. In figure 20, using data from more recent cruises, the longitudinal variations in level of the sea surface over the 400-db. level are shown for the span between 100° W. and 140° E. longitude. Data from stations between 00°30′ N. and 00°30′ S. were used. The 400-db. level was chosen in order to increase the number of available stations. The slope from Montgomery and Palmén's report is also shown.

Of particular interest to this discussion is the slope between 100° W. and 140° W. For comparative purposes, the data from *Smith* cruise 35 (August–October 1956) and cruise 38 (January–March 1957) have been added. It may be seen that the slope during Eastropic was steeper than that for either of these two cruises or for the mean. Comparative values, 120° W. to 140° W., are: mean, 4.5×10^{-8}; *Smith* cruise 38, 5.3×10^{-8}; and Eastropic, 13.1×10^{-8}. A reversal in the calculated slope of the sea surface during Eastropic is evident near 120° W. (fig. 20). This reversal results from the deepening of the thermocline east of 130°–120° W. (see fig. 5) and the accompanying increase in depth of the warmer, less-saline, and thus less-dense waters of the mixed layer.

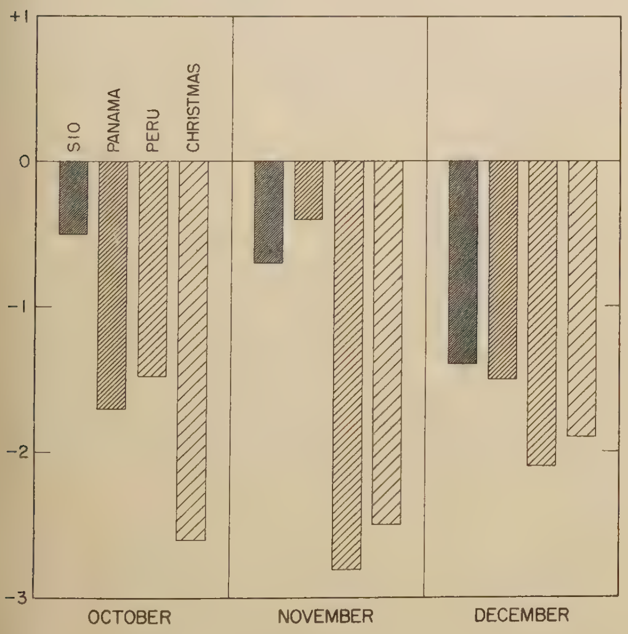

Figure 19.—Surface temperature anomalies (° F.) for four stations in the eastern Pacific for October, November, and December, 1955.

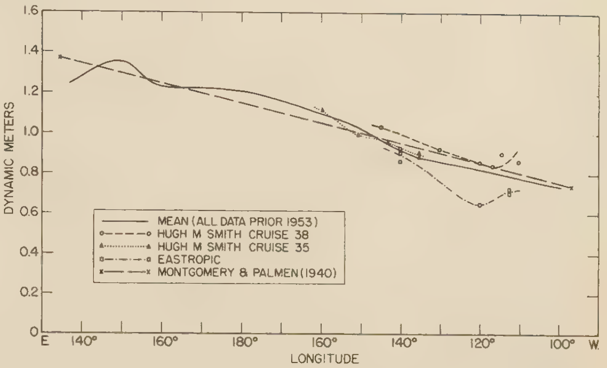

Figure 20.—Longitudinal slope, sea surface, 0/400 db. level.

The same features and conclusions can be inferred from the distribution of the depth of the 70° F. isotherm along the Equator (fig. 21). This isotherm is normally found near the center of the depth range of the thermocline (Austin 1954a), and thus exhibits the same variations in depth as the thermocline.

In figure 21, prepared from all available BT data from POFI files and those furnished by Scripps Institution of Oceanography, between 2° N. to 2° S., the variations in depth of the 70° F.

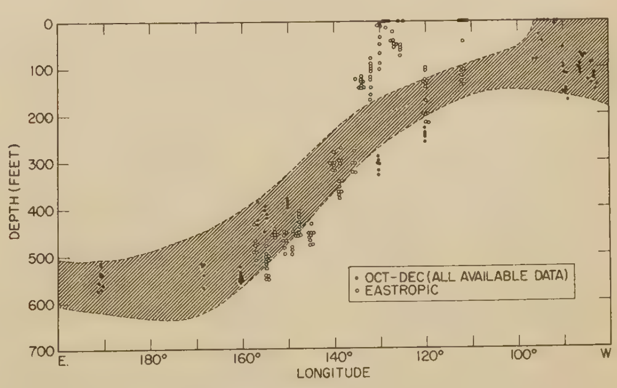

Figure 21.—Depth of 70° F. isotherm, 2° N. to 2° S.

isotherm, 80° W. to the 180th meridian are shown. The hatched "envelope" shows the approximate range of variation in depth among these data. Part of this variation results from seasonal fluctuations in the depth of the thermocline (Austin 1958), and part from the ridgelike configuration of the thermocline between 2° N. and 2° S. latitude. Data obtained prior to Eastropic for the months October through December (Eastropic cruise period) are shown by the solid dots and those during Eastropic by the small circles. Comparison of the mean (a curve through the center of the hatched band), the October–December data (dots), and Eastropic data (circles) demonstrates the comparatively steep slope of the thermocline during Eastropic. It is concluded that the comparatively steep slopes of the sea surface and the thermocline are associated with a more than normally active zonal circulation.

In the section describing the vertical distribution of temperature, we mentioned the 2-layer system which is typical of the tropics—the essentially homogeneous water from the surface down to the top of the thermocline, the thermocline (stable layer) through which the temperature decreases rapidly with increasing depth, and the extensive depth range below the thermocline to the ocean floor through which there is but a comparatively slight further decrease in temperature. This situation is typical of waters in the low latitudes throughout the seasons. In the middle and high latitudes, however, a deep mixed layer exists at the end of winter. As the season progresses, the depth of the mixed layer decreases to the midsummer minimum and the depth of vertical turbulence is thus progressively restricted.

The development in the spring of the seasonal thermocline is termed "stabilization" by Sverdrup (1953, p. 291). He demonstrated that the onset of stabilization following the period of deep winter mixing played an important role in the vernal increase in biota. In the low latitudes, there is no such period of stabilization—the vertical density structure during all months is characterized by a mixed layer below which the density increases rapidly with depth and turbulence is suppressed. Therefore, when considering geographical and temporal variations in measurements of the biota in tropical oceans, we must look for mechanisms that will affect the degree of stability or the depth of this stable layer in relation to the compensation depth. Within the area studied from the *Smith* during expedition Eastropic, we have mentioned several such mechanisms, including divergence of the surface waters and upwelling at or near the Equator, the effects of sheer and associated mixing at the boundaries of opposing currents, and the shallowing of the stable layer to a depth that will bring it within the euphotic zone, e.g., at the northern boundary of the Countercurrent. Although there may be seasonal variations, these mechanisms are all primarily related to horizontal and vertical transport features (as contrasted with the spring warming and stabilization and the fall cooling and overturn in the higher latitudes).

In higher latitudes, following stabilization, the nutrients in the mixed layer are quickly depleted by biological utilization and fallout of the organic material into or beneath the stable layer. Until the fall overturn and associated replenishment from below, the nutrient concentration in the mixed layer represents, primarily, a balance between utilization by the phytoplankton and the biological regenerative processes within this layer, with vertical diffusion playing a comparatively minor role. This situation characterizes vast areas of the tropical oceans during all months of the year. In figure 22, the vertical distribution of various properties is shown to illustrate conditions within the mixed, the stable, and the deeper layers at a position in the region of convergence north of the Equator (3° N.). It is to be noted that, at the particular station illustrated, within a very limited range of depth ($\leq$50 meters), there is an abrupt change in the fields plotted. The temperature decreases nearly 10° C., the thermosteric anomaly nearly 300 centiliters per ton (60 percent of total change, surface to 800 meters) and, of particular biological importance, the phosphate suddenly increases from 0.6 to 1.4 μg.at./L. The other nonconservative property, oxygen, decreases from nearly 4 ml./L. to slightly less than 2.0 ml./L. within the same depth increment.

Nearer the Equator, however, the vertical distribution of properties differs somewhat from that shown in figure 22. In the discussion of the vertical distribution of oxygen, we described a feature with waters of comparatively high oxygen content that was positioned beneath the Equator. In each

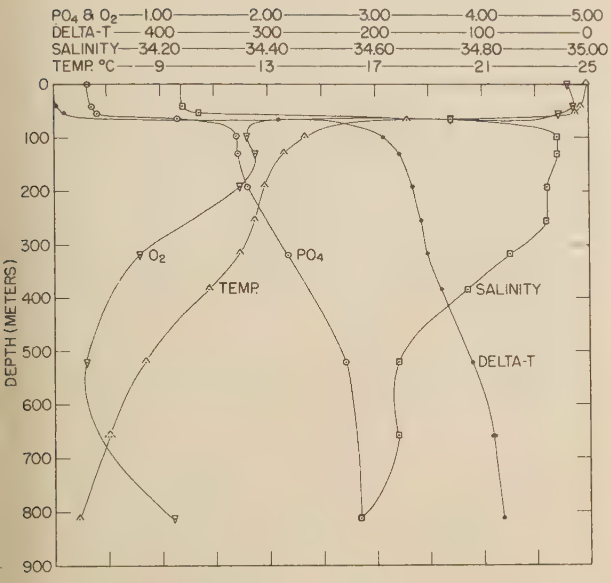

FIGURE 22.—Vertical distribution of temperature (° C.), density (cl./ton), oxygen (ml./L.), and phosphate (µg.at./L.) from *Hugh M. Smith* station 4, 03°13′ N. latitude, 110°12′ W. longitude.

of the four sections shown in figure 11, this feature extended vertically from within or immediately below the thermocline to a maximum depth of between 300 and 400 meters and was approximately 200 miles wide. The oxygen content near its center was 2.8 to 3.0 ml./L. at 140° W., decreasing eastward to 2.5 to 2.7 near 100° W.

Consideration of the possible causes for this geographically restricted feature leads to the conclusion that it is the result of advection. In the first place, the deeper waters are essentially isolated from the oxygen-rich waters of the mixed layer above the thermocline. Even though isentropic principles may not apply near the Equator, the configuration of the density field shown in figure 10 suggests that there is little mixing between the waters in the surface layer and those beneath the thermocline. The oxygen content at depths between 100 and 300–400 meters decreases both to the north and to the south of the Equator.

To emphasize the meridionally limited extent of this feature, the distribution of oxygen on a surface of constant density (180 centiliters per ton) is shown in figure 23. In a narrow band along the Equator, between 140° W. and 120° W., the oxygen values are 3.0 ml./L. or greater. Between 120° W. and 110° W., the values decrease somewhat, then increase again farther to the east. If lateral mixing were significant across the Equator, the feature in question would be eliminated.

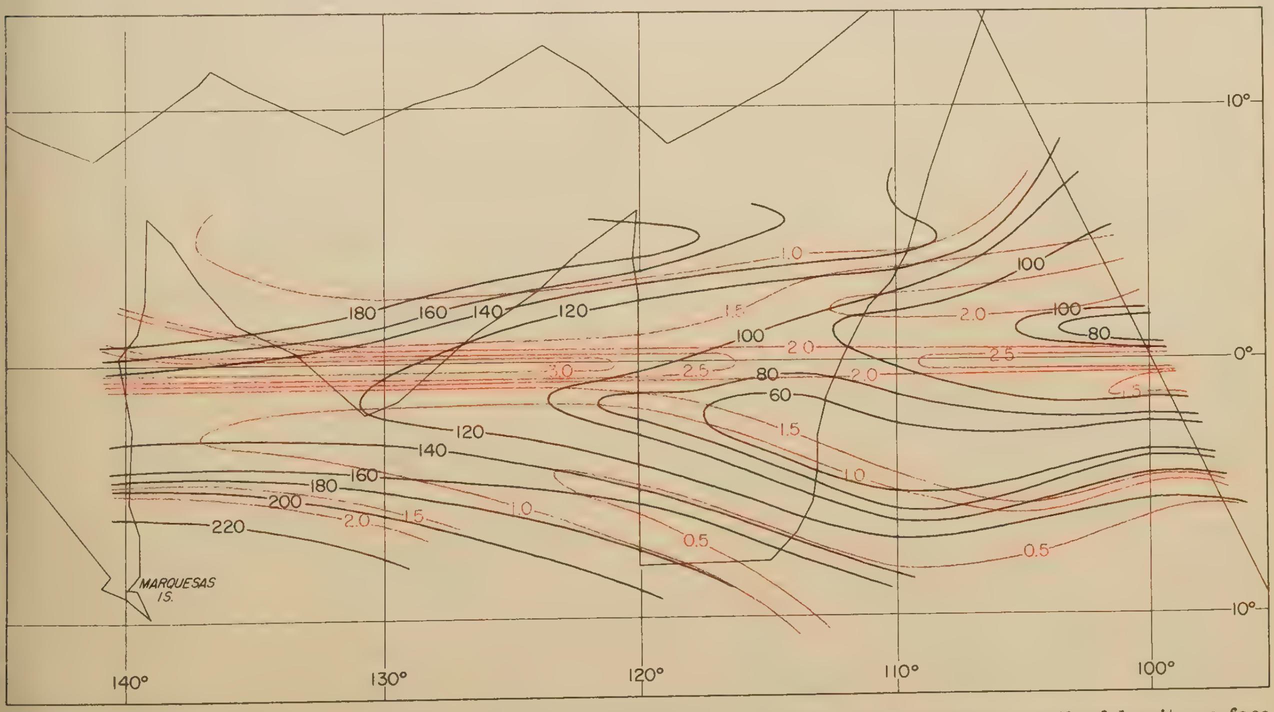

FIGURE 23.—Distribution of oxygen (ml./L.) in red on density surface (180 cl./ton) in black. Depth of density surface in meters.

From consideration of the standing crops of the biota in the euphotic zone near the Equator, oxygen values in the waters beneath the thermocline at the Equator should essentially be depleted and lower than to the north and south unless there was active replenishment. An inference to the standing crop of the phytoplankton may be made from the results of the use of the carbon isotope during expedition Eastropic (fig. 24). The highest rates of photosynthesis were at or very near the Equator where there is enrichment by upwelling (fig. 18). It is reasonable to assume that these higher rates of carbon fixation were associated with the larger standing crops of the phytoplankton. The different rates of photosynthesis among various species in, and the ages of, the populations (whether vigorously growing or senescent) are quantitatively unknown variables. King and Hida (1957, figs. 8 and 10) have shown that the standing crop of zooplankton reaches a maximum between approximately 1.5° N. and 1.5° S. latitude.

These facts and our present knowledge of the pattern of flow near the Equator lead to the conclusion that there is advection of waters with higher oxygen content from the west by the Equatorial Undercurrent. This subsurface, easterly directed flow was first reported by Cromwell, Montgomery, and Stroup (1954). They observed that the Undercurrent was both in the lower part of the surface layer and in the upper part of th thermocline. Its total depth range, however, wa not determined.

More recently, Knauss and King (1958), presenting preliminary results of a detailed survey o the Undercurrent made at 140° W. longitude, report that the vertical extent of the Undercurren is between about 30 and 300 meters with the highest easterly velocities (2.0 to 3.5 knots) recorded a a depth of 100 meters. The Undercurrent wa symmetrical about the Equator. At 2° N. and 2 S. latitude, the average thickness had decreased t 30 meters and the average maximum velocity t 0.6 knot. Of particular interest to the discussio of the results from expedition Eastropic, Knaus and King report that during the period of thei cruise (March–June 1958), the Undercurren showed no diminution in velocity between 140° W and 92° W. and that the depth of its core ros from 100 meters at 140° W. to 42 meters at 98° W Farther to the east, at 95° W. and 92° W., it onc again deepened. At 89° W. the Undercurren was missing.

In the section on vertical distribution of temperature (fig. 6), we discussed the configuration o the isotherms, particularly in the thermocline, a related to the Undercurrent. Between 2° N. an 2° S. there was a spreading of the isotherms, resulting in a shallow ridge and a deeper troug

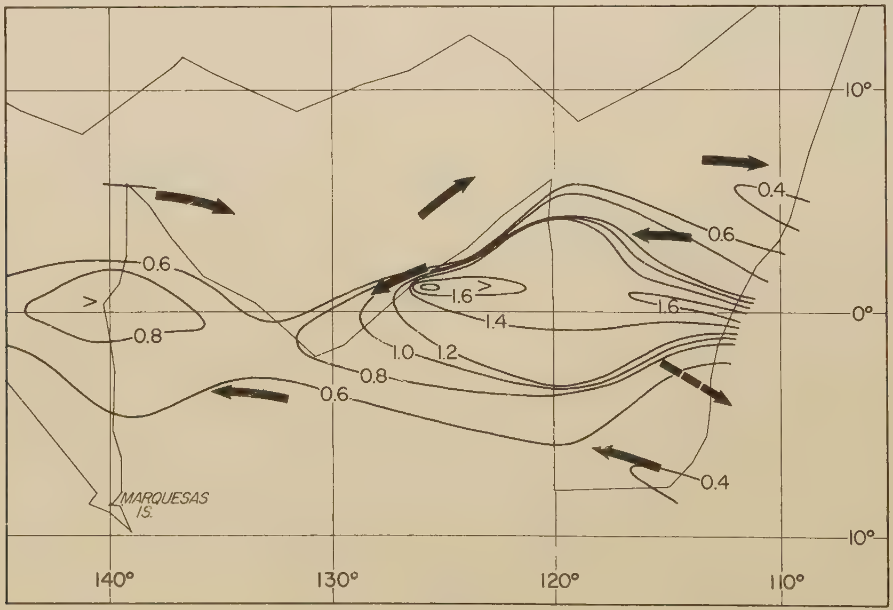

FIGURE 24.—Rate of carbon fixation (mg.C./hr./m.^{3}) by photosynthesis as measured by uptake of the isotope carbon 1
(Data from King et al., 1957.)

about the Equator. This was interpreted as resulting from advection from the west of the somewhat warmer waters of the Undercurrent. Near the Equator, the thermocline shallowed between 160° W. and 120°–125° W. (fig. 5), then deepened once again. Considering these data and the results reported by Knauss and King (1958), it is assumed that, during Eastropic, the core of the Undercurrent exhibited a west-east variation in depth similar to that of the thermocline.

Oxygen and inorganic phosphate are both nonconservative (biologically affected) properties. Their concentrations normally exhibit reciprocal variations in the sea. This was the case in the waters beneath the Equator during Eastropic, at least along the 110° W. section (fig. 13), the only one for which adequate phosphate data are available. Between approximately 2° N. and 2° S., the meridional extent of the Undercurrent, the higher oxygen values previously discussed were accompanied by lower inorganic phosphate values, 1.6 µg.at./L. or less as compared with 2.0 µg.at./L. or greater at comparative depths to the north and south. Thus, the distribution of the two nonconservative properties and of temperature beneath the thermocline at the Equator is largely governed by the easterly flowing Undercurrent, while their distribution in the shallower portion of the thermocline and the mixed layer is largely related to upwelling.

There are various references to the oceanographic conditions along the northern boundary of the Countercurrent which use the words "divergence" or "upwelling." Relative measurements of the standing crops of the marine biota, especially zooplankton, have been used to support the hypothesis that divergence of the surface waters along this boundary has resulted in enrichment within the euphotic zone. Sverdrup et al. (1942, p. 711), suggest that a transverse circulation is superimposed on the flows to the east (the Countercurrent) and to the west (the North and South Equatorial Currents). Such a transverse circulation would require a divergence at the northern boundary of the Countercurrent and a convergence at the southern boundary. Referring o the relative volumes of the plankton samples aken aboard the *Carnegie* as reported by Graham (1941), they suggest that the relatively high volume at *Carnegie* station 151 (13° N.) was associated with a divergence centered near 10° N. (Sverdrup et al., 1942, fig. 219). This biological evidence may be somewhat speculative as Graham (1941, p. 193) states that this sample (station 151) was "not quite comparable as it contained a large colony of salps." The sample (expressed as dry weight and not as volume) was not used by Graham in his analyses of plankton abundance along the *Carnegie's* transequatorial section (his fig. 41).

Jerlov (1956, p. 150), discussing the results of the *Albatross* expedition in the central equatorial Pacific, assumes from consideration of the relative distribution of particles that "there is ascending water movement along σ_t-surfaces which enriches the upper layer with nutrients." His figure 34 shows a maximum concentration of particles at the northern edge of the Countercurrent. Jerlov suggests that the distribution of these particles "largely represents phytoplankton population and plankton remnants, as the supply of terrigenous components in this area must be low."

Austin (1954a) does not recognize the presence of upwelling at the northern boundary of the Equatorial Countercurrent in the central Pacific, but does acknowledge the fact that the shallow thermocline in this area (see fig. 15, this report), coupled with wind mixing, may result in an increase in the biota. A question of semantics may be involved. Austin and Rinkel (in press) have defined upwelling as a local, wind-induced divergence of the surface waters resulting in a mixing of the deeper, cooler, nutrient-rich waters with those at the surface. Within the scope of this definition, there is no evidence of upwelling along the northern boundary of the Countercurrent in the Eastropic data. Although there was a marked ridge in the thermocline, there was no evident cooling of the surface waters (see fig. 14). At the northern edge of the Countercurrent any upwelling would result in a band of more-saline waters and waters with higher phosphate concentrations. Salinities were comparatively low, increasing to either side of the northern edge of the Countercurrent (fig. 17). Phosphate concentrations were low, averaging 0.4 µg. at./L. or less, these to be compared to 0.8 to 1.0 µg. at./L. near the Equator (fig. 25).

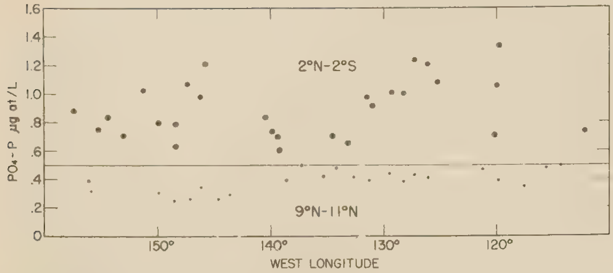

FIGURE 25.—East-west variations in surface inorganic phosphate concentrations (µg.at./L.) between 2° N. and 2° S. latitude and 9° N. and 11° N. latitude.

An important biological consideration is the fact that along the northern boundary of the Countercurrent the thermocline in the eastern Pacific is sufficiently shallow to be within the euphotic zone. If we assume that in these tropical waters seasonal variation in light is not a limiting factor, Sverdrup's concept of critical depth is applicable (Sverdrup 1953). With the thermocline penetrating into the euphotic zone (shallower than the compensation depth, ca. 100 meters), the phytoplankton in the mixed layer is retained within the depth range of active photosynthesis; i.e., not carried by vertical mixing to a depth during the day where respiration exceeds photosynthesis. To the north and south of the northern boundary of the Countercurrent, and west of about 150° W., the thermocline deepens and is normally deeper than the compensation depth.

Biological data from this area are pertinent. King and Hida (1957), discussing the results of POFI's zooplankton program in the central equatorial Pacific, 1951 to 1954, show that zooplankton volumes in the Countercurrent are comparatively low, 180th meridian to 150° W. longitude (ca. 25 cc./1000 m.^{3}) but increase to nearly 45 cc./1000 m.^{3} between 140° W. and 120° W., a volume approximately equal to that of the region of the divergence near the Equator. They also demonstrate (fig. 11) that, between 8° N. and 11° N., the plankton volumes increase west to east (170° W. to 140° W.) as the depth of the thermocline decreases. Thus, the available empirical data suggest that any relative increase in the standing crops of the biota along the northern boundary of the Countercurrent is more directly related to the presence of a shallow thermocline than to a divergence and upwelling in the surface waters.

SUMMARY

A cooperative oceanographic survey of the ce tral and eastern tropical Pacific (expeditio Eastropic) was conducted during the period Se tember–December 1955, with five research vesse participating, representing five agencies: Scrip Institution of Oceanography, Inter-America Tropical Tuna Commission, California Depar ment of Fish and Game, Pacific Oceanic Fisher Investigations (POFI) of the U. S. Fish an Wildlife Service, and the Peruvian Navy.

As POFI's participation in Eastropic, th *Hugh M. Smith* (cruise 31) completed an 86-da 14,000-mile cruise, obtaining information on eas west gradients in temperature, salinity, phosphat zooplankton, and forage fish abundance along th northern boundary of the Equatorial Counte current and along the Equator between 110° W and 156° W. longitude. A survey of tuna bai fish was conducted in the Marquesas Islands an in collaboration with the University of Hawai carbon fixation and chlorophyll measuremen were made on the westbound leg of the cruise.

Sea surface temperatures along the Equat were from 2° to 4° F. cooler than normal; thos in the Equatorial Countercurrent deviated litt from normal. Temperature anomalies for th eastern Pacific, Alaskan waters south to Per were generally negative (−0.6° F. to −2.0° F for the latter half of 1955.

Near the Equator, the observed east-west slo of the thermocline was considerably steeper tha normal, shallowing from near 500 feet beneat the surface at 160° W. longitude to at or ne the surface at 125°W., then deepening somewh to the east.

A pronounced oceanic temperature front, acro which there was a temperature change of appro imately 3° F., was observed near 4° N., 120° W The same or a similar feature was observed (month later) from the Scripps Institution Oceanography vessel, the *Horizon*, near 3° N 120° W.

Calculated current velocities in the warm waters to the north of the front were westerly, 1 to 2.3 knots, decreasing to 0.2-knot westerly flo in the cooler water to the south of the front. I the eastern portion of the area surveyed from th *Smith* (Equator to 4° N., 120° W.), velociti measured from Scripps vessels were as high as 2.0 knots (324° T., measured at 3°08′ N. near 120° W.).

The calculated east-west slope of the sea surface (0/400-db. level) was greater than the mean; 0.66 dynamic meters at 120° W. (mean=0.85) sloping upward to 0.90 dynamic meters near 140° W. (mean=0.92) for a difference of 0.24 dynamic meter as compared with 0.07 for the mean.

Upwelling and wind mixing, coupled with a shallow thermocline, resulted in considerable enrichment of the surface waters along the Equator. Concentrations of inorganic phosphate at the surface were between 0.8 and 1.2 μg. at./L. in the region of the shallow thermocline (near the Equator and 125° W. and near 4° S. and 115° W.). Phosphate concentrations in the surface waters of the Countercurrent and along the northern edge of the Countercurrent were uniformly low, ≦0.4 μg. at./L.

Cooler than normal surface temperatures, comparatively steep east-west slopes in the sea surface and the thermocline, comparatively high calculated and measured current velocities, and high inorganic phosphate concentrations in the surface layer, all suggest the horizontal and vertical circulation features, 5° N. to 5° S. along the Equator, were more dynamic during Eastropic than normally observed.

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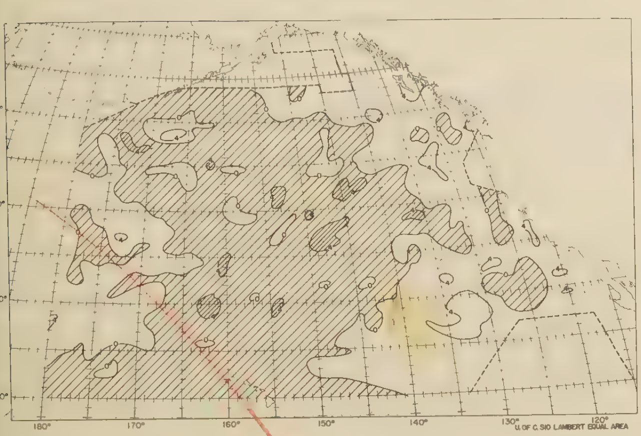
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140°
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120°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 31. Jan. 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 than 1957.

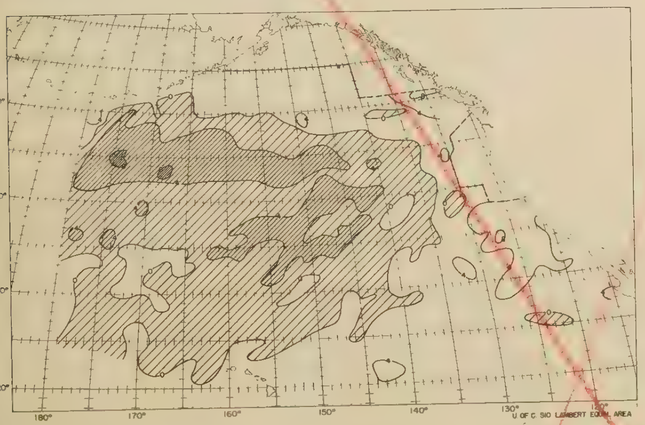
50°
40°
30°
20°
180°
170°
160°
150°
140°
130°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 32. Feb. 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 and 1957.

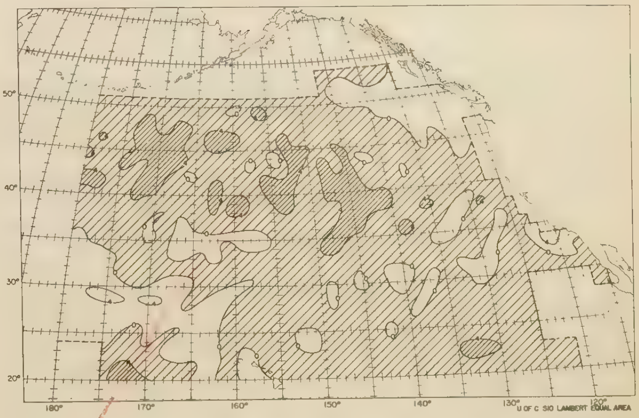
50°
40°
30°
20°
180°
170°
160°
150°
140°
130°
120°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 34. April 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 than 1957.

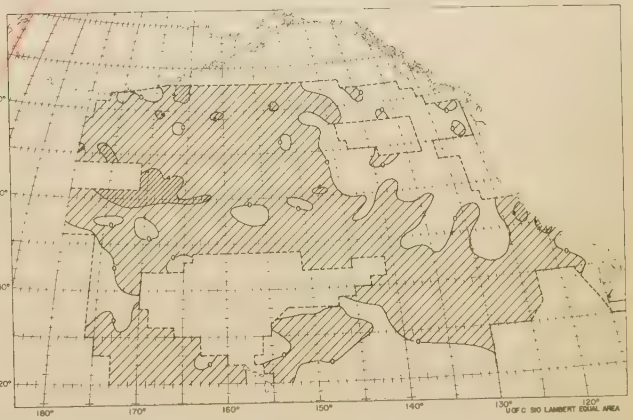
50°
40°
30°
20°
180°
170°
160°
150°
140°
130°
120°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 35. May 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 than 1957.

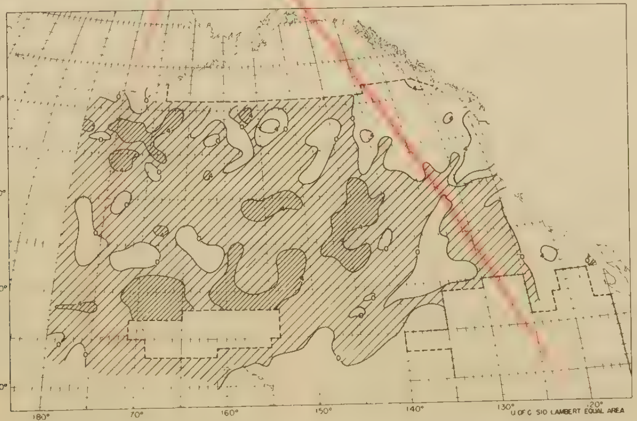
50°
40°
30°
20°
180°
70°
160°
150°
140°
130°
120°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 33. March 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 than 1957.

SUMMARY, 1955-57 OCEAN TEMPERATURES, CENTRAL EQUATORIAL PACIFIC

THOMAS S. AUSTIN

PACIFIC OCEANIC FISHERY INVESTIGATIONS

MONTEREY AND MARIPOSA DATA

Late in 1956, POFI made arrangements whereby two passenger liners, the SS *Mariposa* and the SS *Monterey,* were to collect surface temperature data and salinity samples once each watch (four-hour intervals) during their passage, Honolulu to Tahiti and/or Pago Pago and return. As a result of these arrangements, at least one surface temperature and one salinity section, along the courses traversed by these vessels, are available for each month, November 1956 to present.

In figure 36, the temperature data have been expressed as anomalies from the mean; positive anomalies have been shaded. Along the top of the panel for each month, the inclusive dates for the section, the vessel(s) (MO-*Monterey,* MA-*Mariposa*), and the ports of call (H-Hawaii, T-Tahiti, and PP-Pago Pago) are given. When both vessels made the run during any one month, their observations have been averaged and a single curve drawn. Mean temperatures, to which the observed temperatures were algebraically compared, were taken from the Monthly Meteorological Charts of the Western Pacific Ocean.[1]

When departing Honolulu (right end of each panel) (Fig. 36) and proceeding south, the vessels crossed the

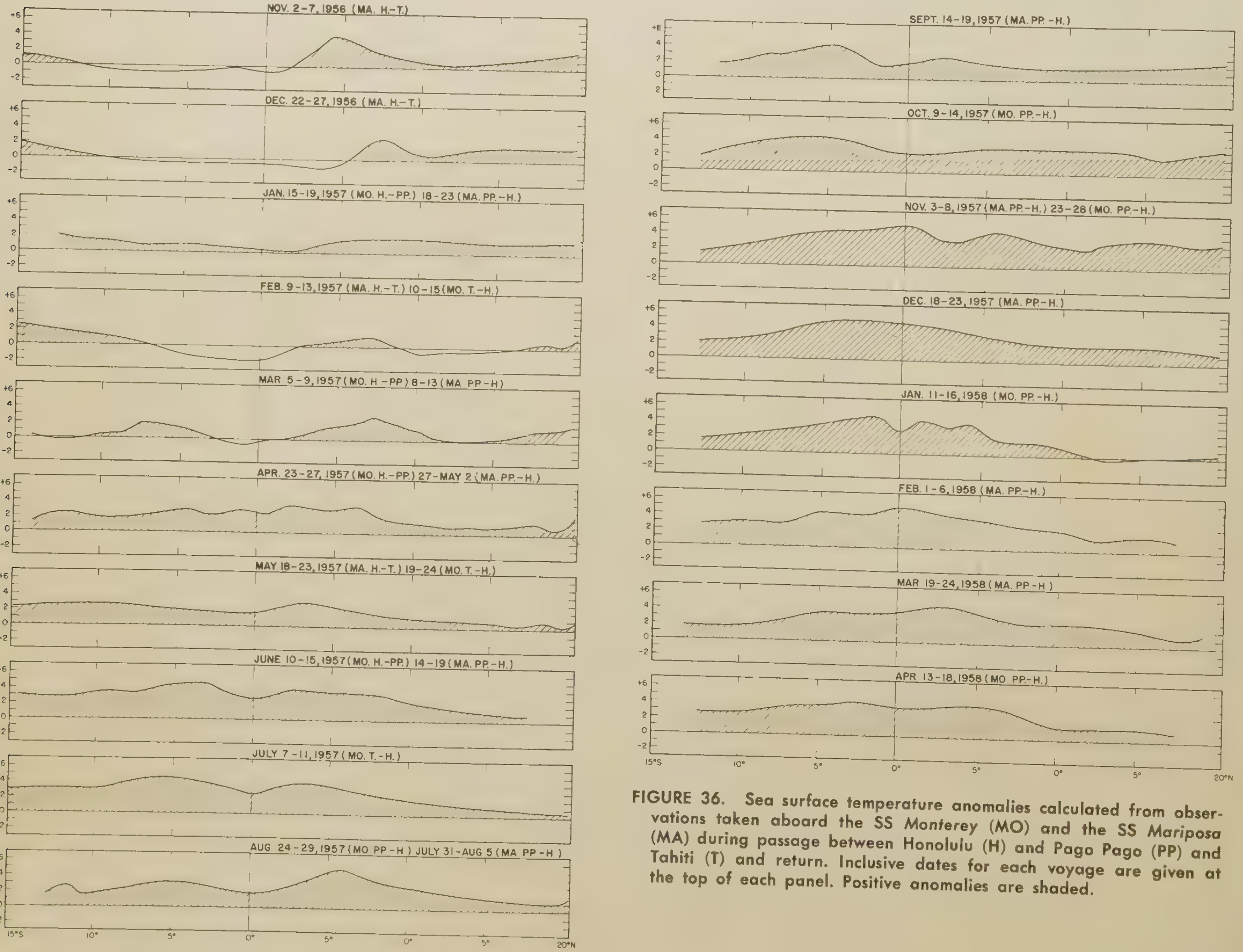

FIGURE 36. Sea surface temperature anomalies calculated from observations taken aboard the SS Monterey (MO) and the SS *Mariposa* (MA) during passage between Honolulu (H) and Pago Pago (PP) and Tahiti (T) and return. Inclusive dates for each voyage are given at the top of each panel. Positive anomalies are shaded.

---

[1] British Air Ministry, Monthly Meteorological Charts of the Western Pacific, MO-484, 120 p.

westerly flowing North Equatorial Current to about 10°N. latitude, the easterly Equatorial Countercurrent, 10°N. to 5°N., and then the westerly South Equatorial Current, 5°N. to Tahiti or Pago Pago. At or near the Equator, they passed through the surface waters which are normally cooled by the upwelling from subsurface layers.

Referring to figure 36, April 1957 was the first month during which the anomalies were positive for the entire passage. With the exception of the northern portion of the leg for January 1958, the anomalies remained positive for each month of the year, April 1957 through April 1958. It would appear that, in general, the equatorial surface waters in the Southern Hemisphere warmed somewhat more slowly, but once warmed, maintained the positive anomaly at a consistently higher level than for the surface waters north of the Equator.

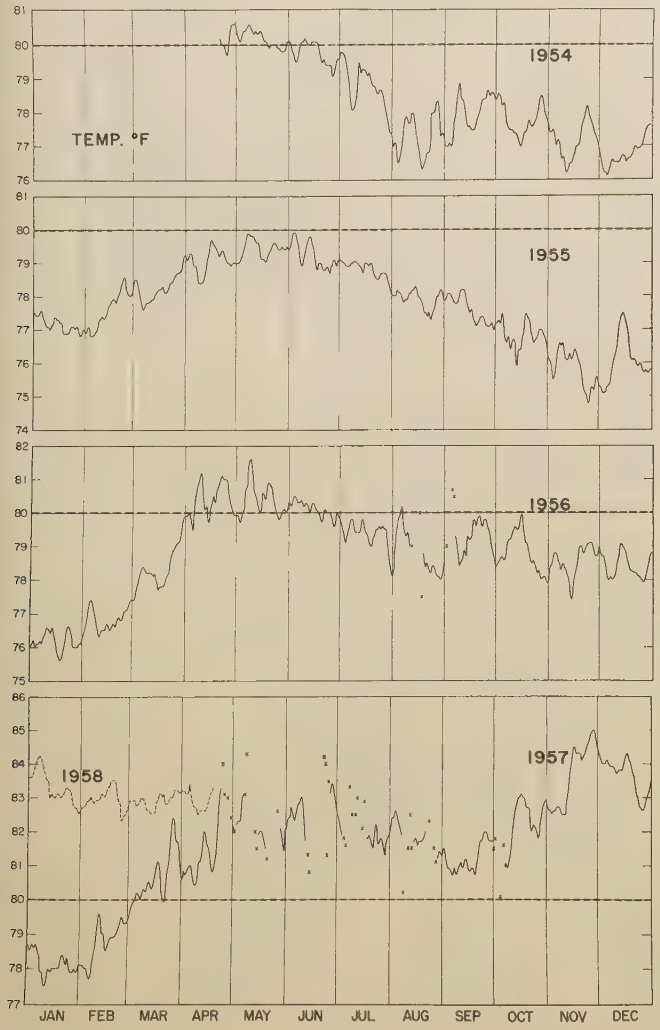

FIGURE 37. Five-day moving averages for daily sea surface temperatures recorded at Christmas Island (2°N., 157°W.), one of the Line Islands group. Observations are taken along the lee shore near the seaward edge of the reef. An "x" denotes observed temperature for days within periods during which the five-day moving average could not be calculated.

CHRISTMAS ISLAND DATA

In early 1954, POFI, in cooperation with the U. S. Weather Bureau, established a weather station on Christmas Island--an atoll of the Line Islands group centered near 2°N., 157°W. At the same time, arrangements were made for daily sea-surface temperature observations and weekly salinity samples to be taken at a position near the seaward edge of the reef, lee (western) side of the island.

The results of the daily temperature observations have been depicted as a five-day moving average in figure 37; as monthly means in figure 38. In figure 37 the small "x's" denote the observed temperature for days within periods during which a break in the record did not permit calculation of the five-day moving average.

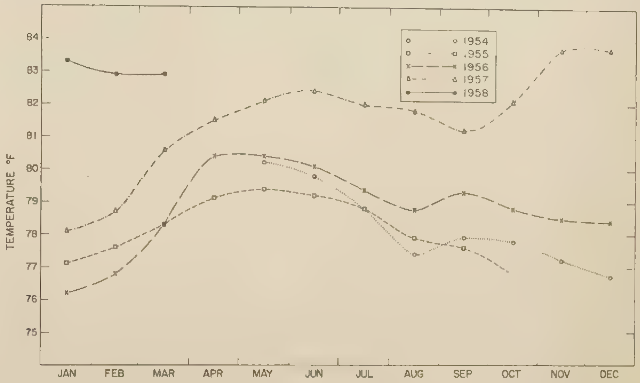

FIGURE 38. Thirty-day mean sea surface temperatures, Christmas Island station.

The comparatively warmer surface temperatures observed at the Christmas Island station during late 1956, all of 1957, and early 1958 are quite evident on both figures 37 and 38. If we start with November-December 1955, we note that the temperatures were the coolest during the period of the observations. This situation, according to Rodewald (1956) was characteristic for the winter of 1955, Alaskan waters south to the coast of Peru. The surface temperatures then increased in a rather normal fashion, reaching the 1956 maximum during April and May. Subsequently there was cooling, but the 1956-57 winter minimum (78.5°F.) never did reach the same low as in 1954 (76.5°F.) or 1955 (75.0°F.). The 1957 spring warming continued until the surface temperatures reached 82° to 83°F., 2°F. warmer than for the same period during the years 1954-1956. Although the anticipated summer cooling was evident, June through September 1957, the normal trend was marked by reversal towards further warming (October), and the midwinter minimum was absent during 1957-58 (Figs. 37 and 38). Comparison of the dashed curve (1958), lower panel, figure 37, with the solid curve (1957) for the months January through April, shows that the January 1958 temperatures were approximately 6°F. warmer than those for January 1957.

Referring to figure 38 which shows the mean monthly temperatures, the curves for 1954, 1955, and 1956 show a reasonable degree of similarity. During the latter half of 1956 and all of 1957, however, the surface temperatures at the station were consistently higher than for the previous years of the series. The question arises: how indicative of subsurface conditions are these surface temperatures? Frequent meridional temperature-depth sections, at no more than monthly intervals, would be required to adequately answer such a question.

Some data for consideration of variations in temperature-depth distribution, 1957-1958 compared with previous years, are available from BT sections, Honolulu south to the Equator or to the Marquesas. 140°-150°W. longitude. Two sets of such sections have been compared in figures 39 and 40. The 60°, 70°, and 80°F. isotherms for each BT section are included; those for the particular month in 1957 as a solid curve, those for the chosen previous year (1955) as a dashed curve.

The September 1955 and October 1957 sections are very similar; the December sections comparatively dissimilar. On the December 1955 section, the only surface and subsurface waters observed to be 80°F. or above were those of the Equatorial Countercurrent.

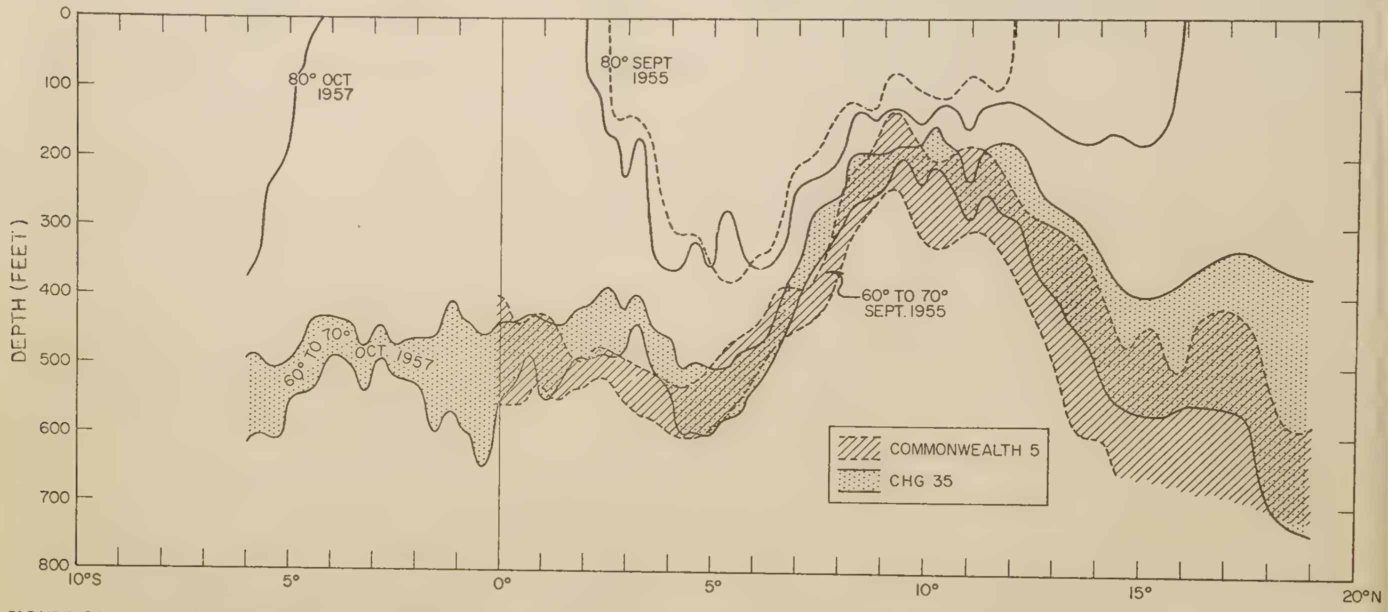

FIGURE 39. Vertical temperature distribution (80°, 70°, and 60°(F) isotherms) from BT sections made during *Commonwealth* Cruise 5, September 1955 (dashed contours) and C. H. *Gilbert* Cruise 35, October 2-7, 1957 (solid contours), 140°W.-150°W. longitude.

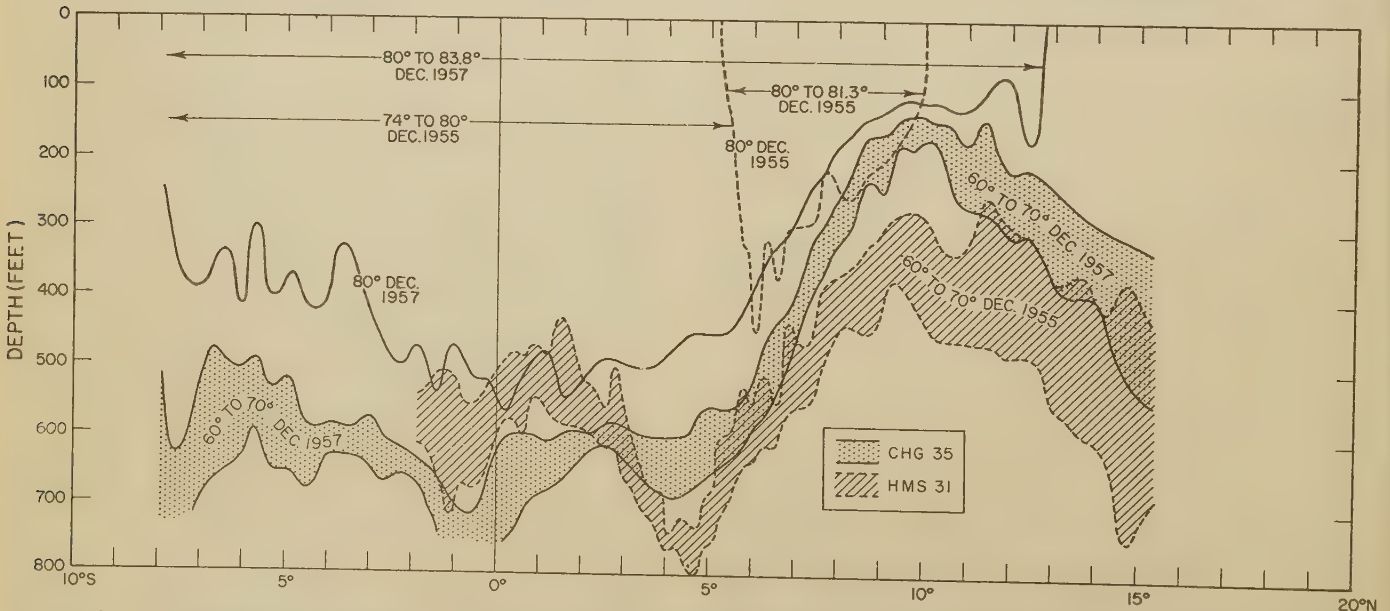

FIGURE 40. Vertical temperature distribution (80°, 70°, and 60°(F) isotherms) from BT sections made during *H. M. Smith* Cruise 31, December 1955 (dashed contours) and C. H. *Gilbert* Cruise 35, December 1957 (solid contours), 140°W.-150°W. longitude.

South of the countercurrent, the temperature of the waters above the thermocline were generally 74° to 80°F. In contrast, along the December 1957 section, temperatures in the surface layer, from 12°N. to at least 8°S. latitude were 80°F. or above, reaching a maximum value of 83.8°F. in the countercurrent. The 80°F. isotherm reached depths of 500 feet or more near the Equator. From consideration of surface temperatures at Christmas Island, figure 38, the means for early October and for December 1957 were 3°F. and 6°F. warmer, respectively, than the same months, 1955. From consideration of the subsurface distribution (Fig. 39) the subsurface temperature conditions were very similar during September 1955 and early October 1957, not clearly reflecting the apparent warming, while in a similar consideration of the two sections for December 1955 and 1957, figure 40, the surface and subsurface differences are strikingly evident.

If we compare the October and December 1957 sections (shaded areas and solid curves, figures 39 and 40, at least two interesting points may be seen. First, within approximately 90 days, a large quantity of warm water had apparently moved into the area, too large a quantity to be attributable to local effects such as that of insolation. In general, with persistent southeast trades, advection through 150°W. by the westerly South Equatorial Current would transport cooler waters normally found to the east of 150°W. Upwelling would cool the surface waters near the Equator. This situation, as inferred from variations in depth of the 60°F. and 70°F. isotherms, is illustrated on both the December 1955 and the October 1955 sections. These isotherms reach a maximal depth near 5°N., decreasing in depth toward the Equator, then increasing again in the Southern Hemisphere. The resulting ridge centered near the Equator reflects both westerly transport and upwelling. However, in the December 1957 section (Fig. 40), the same isotherms deepen continuously, 5°N. to the Equator, then slope upwards in the Southern Hemisphere. The trough thus formed near the Equator suggests, in contrast to the situation for December 1955 and October 1957, easterly transport through 150°W. of the warmer surface waters from the west and little or no upwelling. That such transport may have been the case is supported by an observation of a 5-knot easterly set, 00°30′N. to 02°30′N.; 160°W. reported by the SS *Monterey* on November 25, 1957.

Available data are too few to permit any more than speculation as to what processes may have been involved in causing these variations between the October and the December meridional, temperature-depth distributions. In general terms, there is a progressive east-west warming of the surface waters in the Equatorial Pacific, with the most pronounced east-west gradient to be found east of the 180th meridian. The sea surface in the Western Pacific is 0.8 to 1.0 dynamic meters higher than in the east; the thermocline progressively shallows, west to east. The existence of and variations in these situations are related to the presence of and variations in the trade wind system.

We mentioned above that vertical distribution of temperature for the October BT section suggested westerly flow of the surface waters, 5°N. to the southern limit of the section and upwelling centered about the Equator. This is the ''normal'' situation with the easterly component of the trades. With a relaxation of the trades, and particularly with a comparatively high frequency of westerlies, one could postulate a reversal in flow of the surface waters (and the undercurrent reaching the surface), with the warmer waters from the west becoming evident through the 150°W. section. A second factor leading to warmer waters in the surface layers—westerly winds are *convergent* in terms of surface flow at the Equator, thus there would be no divergence of the surface waters and no upwelling of the deeper, cooler waters. From advance indications of the available data, this may have been the situation during the December 1957 section.

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THE OCEANOGRAPHIC SITUATION IN THE VICINITY OF THE HAWAIIAN ISLANDS DURING 1957 WITH COMPARISONS WITH OTHER YEARS

GARTH I. MURPHY, KENNETH D. WALDRON and GUNTER R. SECKEL
Pacific Oceanic Fishery Investigations

During the past three years POFI initiated a number of temperature and salinity monitoring stations in the Central Pacific as follows: Oahu, Hawaii; Johnston Island; French Frigate Shoals; Midway Island; Wake Island; Christmas Island; and Weather Station "Victor." The purpose of this network is to develop time series that can be related to variations in the oceanic circulation which, we anticipate, can in turn be related to variations in the distribution of skipjack and other tunas. At the present only the Christmas Island and Oahu stations have been established long enough to provide material suitable for discussion. The Christmas Island station is reported on elsewhere, leaving the Oahu station and other pertinent observations in the vicinity of Hawaii for consideration here.

SURFACE TEMPERATURE AND SALINITY AT OAHU

The Koko Head station is occupied each Tuesday morning about 9 a.m. A bucket of water is dipped from the cliff, temperature measured and the salinity sample returned to the laboratory for titration. There are no coral reefs at the station; the depth drops off abruptly to about thirty feet below the cliff and then quickly falls off to deep water. There are no nearby streams either, and thus the location is close to ideal with respect to non-interference of shallow water warming and run-off. Offshore surveys conducted simultaneously with the shoreside observations give us further confidence that water samples taken there are representative of general conditions off that portion of Oahu.

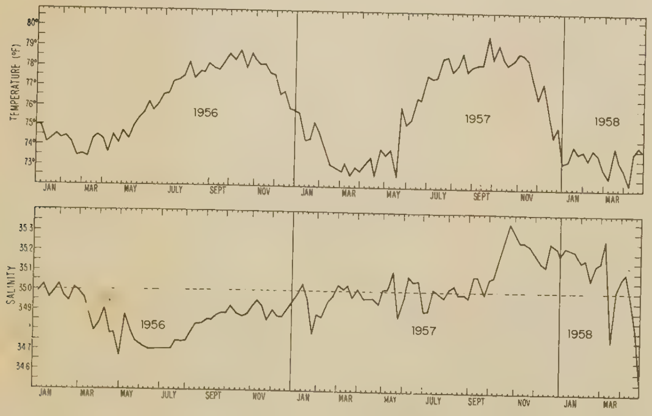

FIGURE 41. Surface temperature and salinity at Koko Head, Oahu.

Two and one-half years' records from this station are plotted on Figure 41. Since primary comparisons will be between 1957 and 1956, it is of some interest to consider the representativeness of the 1956 material. Though not herein documented, our accumulation of records suggests that 1956 was very close to an average year with respect to temperature and with respect to salinity. Weather patterns and biological patterns were also reasonably representative of average conditions during that year. We can then with some confidence treat 1956 as a base and proceed with intercomparisons between 1956 and 1957.

With respect to surface temperature, the pattern in 1957 was similar to 1956 insofar as maximum and minimum temperatures are concerned. However, it is clear that spring warming was accelerated in 1957 and the winter cooling was also more accelerated. These data in themselves are not clear evidence of a significant change in the advection pattern.

Surface salinity (Fig. 41) shows 1957 to be markedly different from 1956. The March-May decline in salinity followed by a gradual rise in salinity from about the first of July onward did not occur in 1957. Instead, salinity in 1957 remained almost constant until mid-September when it rose abruptly to levels higher than those ever recorded. This was followed in the spring of 1958 by an abrupt decline to what might be regarded as normal spring salinities. The decline however was short-lived, and during the first week of April salinities again rose to about 35.0‰ and remained at that level, at least through the third week in May (not included in plot on Fig. 41).

The major trends in the salinity data can only be accounted for by advection; for instance, the March-May decline illustrated by 1956 occurs at a time of decreasing rainfall. Each of the other major trends illustrated either were contrary to what might have been expected from rainfall and isolation, or could not be accounted for by these factors. However, at least some of the short-term changes in salinity can be correlated with rainfall, the most graphic example being the mid-March, 1958 decline; this occurred coincidental with a rainfall of about two feet within a 24-hour period.

From the data on figure 41 we can safely conclude that there are seasonal changes in advection in the vicinity of the Hawaiian Islands and that the typical seasonal changes did not occur in 1957; rather, the island area was brought under the influence of water masses that do not normally influence the area.

The data on figure 41 replotted in smooth form on figure 42, graphically illustrate the difference between the two years. The treatment on figure 42 is in essence a T/S curve, time being the third and non-linear variable, rather than depth. It is interesting to note that many features of the basic pattern were similar during the two years, very possibly reflecting similar patterns

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FISHERIES AND THE FUTURE

Vernon E. Brock[1]

The population of the world is increasing rapidly and the concurrent demands on the natural resources of this planet grow even faster. The exploitation of natural resources is accelerated not only because there are more people, but because they desire, and to some degree attain, higher standards of living.

Among the natural resources subject to accelerated harvest are the fisheries. The use of the world fisheries in a fashion best designed to sustain yields of increasing magnitude in future years will generate a series of problems of great difficulty and interest. I propose to speculate about the nature of these problems and some possible solutions.

Fisheries belong to a group of natural resources that are living and, by virtue of being alive, are self-renewing. In contrast, most mineral resources are not being regenerated—at least at a sufficiently high rate to effectively postpone the date of their exhaustion. Some nonliving resources, such as soil or water, are renewed.

For the renewable resources, both living and nonliving, the harvest must not, on a sustained basis, exceed the rate of replenishment. The replenishment of that taken by harvest is analogous to interest, but for most of the living resources it, unlike interest, cannot be effectively used to increase capital. If it is not used, it disappears and the failure to recognize this fact has distorted some thinking concerning the management of renewable resources.

Nonrenewable natural resources produce no interest; our use constitutes a consumption of capital, with the likelihood of its ultimate exhaustion. Patterns of use that tend to recirculate would serve to extend the supply as would the use of substitutes. Ultimately, on a self-contained earth, with the energy of the sun as its only significant extraterrestrial import, all resources must be renewable; minerals must be circulated rather than dissipated. Of course, the importation of minerals from extraterrestrial sources would reduce this requirement.

The problems of management of the renewable resources, such as fisheries, are essentially problems of controlling the magnitude of harvests so that replenishment by reproduction is not consistently exceeded and of managing the resource and the associated environment so as to maximize replenishment.

Insofar as our needs are satisfied by yields below that added annually by reproduction and recruitment, the task of managing a fishery is one of monitoring the effects of exploitation, to see if indeed the yields are less than can be safely sustained. In addition, work designed to reduce the effort of harvest or to increase the utility of the catch may be desirable under some circumstances.

Those fisheries which are exploited at their highest maximum sustained yield, and thus should be regulated, are the fully exploited or "mature" fisheries. Such fisheries are in the minority; most of the existing fisheries can apparently sustain some increases in yields, while others are but lightly fished.

Implicit in the statement that mature fisheries should be regulated is the assumption that it is a legitimate activity of government to manage a resource so as to sustain its productivity. If the responsibility for fishery regulation is a governmental responsibility, then obviously it is also a governmental responsibility to measure adequately the consequence of regulation. If such measures are inadequate or lacking, justification for regulation disappears. Regulation without adequate evaluation of the consequences is not uncommon, especially at the state government level.

Since many fisheries are neither within the jurisdiction of any one nation nor exploited by citizens of one nation, management may involve treaties among the governments concerned. These treaties usually establish an international commission to manage the fishery or to handle the various questions which arise concerning its exploitation. The international regulation of fisheries by commissions or other analogous groups will certainly increase in the future.

THE NATURE OF THE SEA FISHERIES

Fisheries are a food-harvesting activity akin, in certain respects, to agriculture. Some portions of the catch are used for needs other than food (oils, stock feeds, fertilizers) which, in a fashion, again parallels the use of certain agricultural products.

While the production of the world fisheries is increasing, the yields, as indicated earlier, can doubtless be yet increased by many times, principally perhaps by the development of fisheries for those organisms lightly or not presently exploited.

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[1] Fishery Research Biologist, U. S. Bureau of Commercial Fisheries, Honolulu, Hawaii.

The 1958 yield of world fisheries, both freshwater and marine, was about 33 million metric tons, substantially less than world meat production and far less than the total yield of animal protein from land. Galtsoff (1952) gave the following yields for certain fisheries:

TABLE 1

YIELDS OF FISHERIES
FOR SELECTED AREAS

Area	Lb/Yr/Acre
Sea of Azov	70.3
Sea of Japan	25.3
North Sea	21.9
Mediterranean	13.4
Atlantic	.6
Pacific	.5

Nelson Marshall (1951) estimates that the yields of the fisheries of North Carolina contain only .08 to .06 per cent of the carbon initially bound up by marine plants. These yields vary from 8 to 21 pounds per year per acre. In terms of an efficient utilization of marine productivity, fisheries do very poorly. However, this is due to the nature of the community of living organisms of which the fish are a part.

The economy of the biotic community is based on the growth of plants. Feeding on the plants are various kinds of herbivorous animals, and in turn the herbivores are eaten by predators which may also be prey for yet others. The generation of foodstuffs by feeding and growth drops rapidly from the plants to the herbivores, and from the herbivores to the predators, being least for the climax predators at the end of the food chain. This is true because food dissipated as energy cannot be used for growth and a portion of what is eaten is not digested.

The majority of our more important commercial fish species are predators and are for that reason among the less abundant species in the sea. Their size, their ease of capture, and their palatability are reasons for their being the object of fisheries.

Fishing differs in a fundamental way from farming in that a fisherman harvests but does not cultivate. Progress in fisheries has been, in the main, improvements in methods for harvesting. Such improvements are essential for the expansion of the fisheries and for their profitable pursuit, but will not give any increase in yield for mature fisheries. For such fisheries, improvements may permit the catch to be taken for less cost and/or in less time.

A POSSIBLE PATTERN OF SEA FISHERIES DEVELOPMENT

As our demands for food from the sea increase, additional fisheries will tend to become mature and to acquire thereby a body of regulations designed to control the catch. Ultimately, it may become desirable to consider means of increasing the yield beyond the point of the maximum sustained yield obtained from the unmodified environment. To do this we must increase the productivity of our fisheries and this in turn implies some changes, carefully designed and controlled, in the environment. These changes can be made in either the physiochemical environment or in the biological one, the biotic community. Let us consider this latter suggestion first.

A simple approach would be to fish the lower trophic levels and to fish less selectively; in short, to harvest in a general, rather than a specific way. It may be suggested that the supply of foodstuffs generated in the sea tends to remain more uniform than the individual abundance of the organisms generating and sustained by it. Therefore a broader harvesting base would result in yields less subject to fluctuations than those of individual species, and by being broader, would produce yields of greater magnitude. However, much of the catch may be of little value.

It may be more effective, however, to fish in a fashion that would improve the biotic community as a habitat for the more desirable species. A pattern of fishing designed to reduce predators and competitors and increase the prey of the desired species would have this effect. By such tactics, we would, in a sense, be cultivating the sea and would approach the pattern of agriculture. The magnitude of the maximum sustained yield of the desirable species should, thereby, be increased.

The manipulation of the biotic community requires the development of fishing techniques of sufficient scope and power to substantially reduce the populations of presently unwanted and comparatively valueless species. While such techniques are certainly not at hand, perhaps some now in their beginnings, such as electrofishing, will provide adequate means, singly or in combination with others, to accomplish this.

Should we succeed in manipulating the biologica environment to an adequate degree, further increases in the yield of fisheries may be attained through the development of high yield varieties by selective breeding. Such an accomplishment, together with the manipulation of the biotic community, would thus add two important techniques of agriculture to the management of fisheries. This would represent a technologica level equivalent to cattle ranching.

If we could change or manipulate the sea itself in some fashion, the effect on fisheries could be enormous Some slight shifting of the flow of ocean current would change water temperature and the characte of the environment profoundly. The stabilization o current flow to prevent long or short term shifts may be as important.

The decade of lower than normal sea temperature off southern California, through the late nineteen forties and fifties, has been considered as an importan factor in the virtual disappearance of the California sardine and the collapse of its fishery. The incursion of warm water off Peru, the "El Nino," has a destructive effect on the marine biota of this area, often causing a tremendous reduction in the guano bird population by reason of the unavailability of th Peruvian anchovy, its principal food.

While the warm surface waters of the tropic supply an ideal environment for life, the loss o nutrient elements to the depths where light is insufficient for the growth of plants often makes the upper sunlit waters comparatively barren. A means of bringing the waters from the dark, cool depths to the surface would restore the lost nutrients and thereby multiply the productivity of the surface waters.

In a sense, the manipulation of the physical environment of the sea itself, together with the manipulation of the biological environment and of the genetic constitution of the stock of organisms subject to a fishery, would give the fisherman the major techniques of the farmer, and fisheries would begin to approach the technological level of argiculture.

I have discussed some ways in which the productivity of the sea may be increased; let us consider some means of accomplishing these ends. What do we need to know, and what must we be able to do to bring about such changes? For some the magnitude of the task is so great that I can suggest very little as to how we may go about it. I am like a cave man attempting to plan a space ship—the plans are likely to be rather vague.

Presently our ability to manage a fishery is restricted to the regulations of fishing effort, useful for mature fisheries. The usefulness of these regulations, however, is dependent on how well we can establish the maximum sustained yield for a fishery. This is a figure arrived at by the examination of the effects of catches made in the past on the stock and on recruitment. If variations other than fishing have little effect on recruitment, the magnitude of this figure may adequately be established. However, where recruitment responds significantly to environmental fluctuations as well as to the number of spawning fish, the efficient utilization of the fishery will necessitate measurements of the effects of these environmental fluctuations. In short, we need better and more accurate measures of the magnitude of the stock of fish and better understanding of the effects of both fishing and environment.

Beyond this, we need to understand the effects of fishing, not alone on the species fished, but on the associated species. The reduction in the numbers of a species must impose adjustments on its prey, its competitors, and its predators, thereby altering its own habitat favorably or otherwise.

Given an understanding of the effects of fluctuations in the abundance of some members of a biotic community on the abundance of others, we need capture methods of sufficient scope to make it feasible to manipulate the abundance of these members in a pattern that will maximize the abundance of the more valuable ones.

Granting the possession of fishing methods of the requisite scope, the establishment of high yield characteristics by selective breeding of the desirable species may provide a further means of increasing productivity.

And possibly, by means I hesitate to suggest, we may manipulate the weather and the sea, which could have enormous biological consequences through changes in the atmospheric and marine climate.

These hypothetical stages are given in Table 2.

We have reached stage two for some fisheries, but many are yet in stage one. Whether or not the remaining stages are reached will depend upon the need for food so pressing that even the restless sea must be tamed and its productivity directed towards that end.

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TABLE 2

STAGES IN THE DEVELOPMENT OF OPEN SEA FISHERIES

Stage	*Condition of Fishery*	*Method of Maximizing Yield*
1	Catch insufficient to reduce recruitment. Immature fishery.	Development of markets. Development of more efficient capture methods.
2	Catch sufficient to reduce recruitment. Mature fishery.	Regulate magnitude of catch.
3	Catch increased by increase in recruitment and survival.	Manipulation of fishing effort to alter relative species composition of the biotic community.
4	Catch increased through development of high yield varieties.	Manipulation of the genetic constitution of the stock.
5	Catch increased through improved physical environment.	Manipulation of the physical environment.

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Vernon E. Brock[1])

Fishery Research Biologist
U. S. Bureau of Commercial Fisheries Honolulu, Hawaii

THE INTRODUCTION OF AQUATIC ANIMALS INTO HAWAIIAN WATERS

Contents

1. Introduction 463
2. Reasons for the Introduction of Aquatic Animals 463
3. Description of the Hawaiian Aquatic Habitats 464
4. Nature of the Endemic Hawaiian Aquatic Fauna 465
5. Introduced Species 466
   a) List of Established Introduced Species 467
   b) Supplemental List 1. Species That May Be Established 472
   c) Supplemental List 2. Introduced Species Which Probably did not Survive . . . 475
6. Discussion 477
7. Literature Cited 480

1. INTRODUCTION

The Hawaiian Islands, an isolated oceanic archipelago, have long been of interest to ecologists. The history of the group, since its discovery by Europeans and before, has been a history of successive invasions by new plants and animals and peoples. These invasions were superimposed on an indigenous flora and fauna and rapidly and irreversably altered it. The process of alteration has not been really understood or described. The present account of Hawaiian aquatic introductions is not an analysis of ecological alterations of the fauna of Hawaiian waters. It is rather an attempt to simply record such introductions and additions that have occurred insofar as available documentation permits and to describe, in general, the Hawaiian environment. Many of the less conspicuous aquatic invertebrates which have been fortuitously introduced are not listed. Like insect immigrants, they will quietly continue to establish themselves. Their recognition as immigrants often depends on their ultimate collection and proper identification.

2. REASONS FOR THE INTRODUCTION OF AQUATIC ANIMALS

While the introduction of some of the exotic aquarium fishes, such as *Limia vittata* may well be fortuitous, the majority of the aquatic animals listed here, 54 out of a total of 61, were deliberately introduced. Some of the remaining species may also have been purposefully released, but their establishment is considered fortuitous in the absence of any record.

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The motives for making purposeful releases of aquatic animals are, of course, various, but can be conveniently grouped under the following categories: (1) Pest Control. The general establishment of mosquito fish and the stocking of some species of *Tilapia* in weed-filled irrigation systems were for this purpose. (2) Recreational and subsistence fishing. The introduction of game fish and *Tilapia*, too, were motivated by a desire to improve Hawaiian waters for such fishing. (3) Increased yield from fisheries. Many of the introductions made, were, of course, motivated by this hope. Some, such as the introductions of oysters and clams, bait fish species, and some species of reef fishes, were done largely for this reason. (4) The addition of familiar or ornamental fishes to the fauna. Perhaps many of the unrecorded introductions are of this kind.

This paper constitutes an expansion of my paper of 1952 (BROCK 1952). Much of the additional data regarding introductions since that date are from the records of the Hawaiian Division of Fish and Game.

3. DESCRIPTION OF THE HAWAIIAN AQUATIC HABITATS

The Hawaiian archipelago reaches, in a shallow crescent, 2,575 kilometers across the Pacific basin, between latitude 18°55′ N. and longitude 154°50′ W. to latitude 28°25′ N. and longitude 178°25′ W. This group of islands is ordinarily divided into two parts: the leeward or Low Islands, and the windward or High Islands. The eight High Islands have a total area of 16,667 square kilometers. The area of the ten Low Islands is about 16 square kilometers, but with shoal water areas (depths less than 200 meters) exceeding those of the High Islands.

This arc of islands, trending from Hawaii northwesterly to Kure, arise abruptly from the sea floor as an enormous dike of basaltic lava. The Leeward Islands are greatly eroded and are mantled by coral reefs. The Windward Islands are mountainous peaks 900 to 4,000 meters high and have narrow coral reefs or merely a thin cover of coral on the upper margin of steep submerged slopes.

The lavas of these islands are of various ages and have been, through differences in age and amounts of rain, subject to weathering and erosion in varying degrees. Those areas of most recent lava flows lack any permanent streams, as, for example, the Kona and Kau coasts of Hawaii, which are some 320 km. in length and fall along the base of Mauna Kea, Hualalai, and Mauna Loa. The new lavas of these areas are so porous that rain percolates through, forming a freshwater lens which seeps back into the sea along the shoreline. The windward sides of all the larger islands have streams, but only Kauai and Oahu have permanent streams on the leeward sides. In general, the windward streams tend to enter the sea abruptly with little or no brackish water areas at the mouth, while the leeward streams usually end in an estuary. The Hawaiian streams are subject to heavy freshets and are commonly torrential in their upper portions. Rainfall is occasionally very heavy, exceeding 50 cm. in 24 hours. This results in scouring of the stream beds.

Water temperatures in the streams are cool, considering the latitude of the islands. The important reasons for this are the rapid rate of drop in the streams from the headwaters to the sea and the shade afforded by dense vegetation overhanging the course of the streams. In general, air temperatures fall about 1° C. for each 165 meters of elevation and the water temperatures of a stream, by reason of flow from higher to lower elevations, tend to reflect temperatures for the higher elevations. The lower portions of a stream may range from 20° to 25° C., usually closer to 20° C. Streams in the Kokee area of Kauai, which sustain a breeding rainbow trout population, have temperature ranges between 10° C. to 18° C. depending upon season and degree of shade over the stream. This area is about 900 to 1,200 meters in elevation.

In addition to stream habitats, the irrigation systems, especially of the sugar plantations, supply an important habitat for aquatic animals. In general, the water in the irrigation systems is stored in reservoirs and distributed to the sugar cane fields by ditches or pipes. It is obtained, for the most part, by stream diversions, occasionally from wells. Water temperatures are usually somewhat higher in irrigation systems than in streams by reason of periods of storage in open sun. The reservoirs constitute the bulk of the pond fish habitat available.

Some estuarine habitat is present at the mouths of some streams and in harbors such as Pearl Harbor, Honolulu Harbor, Port Allen, and Hilo.

The Hawaiian marine habitats can be conveniently grouped into three categories: (1) sublittoral or reef, (2) pelagic and (3) benthic. These categories have been characterized in some detail by GOSLINE and BROCK (1960). The introduced species, where purely marine, have been, with one exception, species of the sublittoral region. This region may be defined as that between the surf line and a depth of 50 meters. It includes some coral reefs, rocky and sandy areas, and admixtures of these. The water is clear and the fish fauna of the sort associated with coral reefs. Water temperature, where not locally modified by cooler fresh water escaping into the sea, has a seasonal range from 23° C. to 26° C.

The pelagic region is that of the open sea, and the benthic the sea floor between 50 and 250 meters.

These categories are admittedly artificial to a degree, but do contain distinctive assemblages of species.

4. NATURE OF THE ENDEMIC HAWAIIAN AQUATIC FAUNA

The Hawaiian archipelago constitutes one of the most isolated island archipelagos in the world. The nearest island is Johnston Island, which lies some 1390 kilometers to the southwest and is itself quite isolated. Beginning at approximately 1760 kilometers due south are the Line Islands. The nearest continental land mass is that of North America, which is some 3890 kilometers to the northeast. However, the Hawaiian fauna is clearly of Indo-Pacific origin. Considering the pattern of ocean currents, the origin of the fauna may be primarily from the coasts of tropical Asia which are bathed by the Kuroshio Current System. (GOSLINE and BROCK, 1960.) During the winter months the island chain is usually surrounded by western Pacific water, part of a great eddy of which the Kuroshio constitutes the western and northern boundaries. Because of distance many of the species found in the western Pacific have not apparently been able to reach Hawaii. In some respects the effect of distance on the ability of various species of fishes to reach new areas may be akin to a filter. Those species whose life history patterns permit some sojourn in a pelagic environment have an innate advantage and can thereby traverse reaches of open ocean denied to other species not adaptable at any stage of their life history to the pelagic environment. Because of this, or possibly because of other reasons, the Hawaiian fauna, while clearly derived from the fauna of the western tropical Pacific, is lacking in a number of important elements of that fauna. It is, in a sense, an incomplete fauna, insofar as the inshore and freshwater species are concerned.

The character of the differences between the Hawaiian freshwater and marine fish fauna and that of other portions of the Indo-Pacific faunal region can be illustrated by an examination of the species composition of some groups of inshore and freshwater fishes. For the inshore fishes, the catalogue of FOWLER (1938) of the fishes of Eastern Oceania which included, besides the Hawaiian Islands, the Society Islands, the Marquesas Islands, and the Line Islands, is of interest. Among the sea basses or groupers, genera *Cephalapholis* and *Serranus* (= *Epinephelus*), Hawaii is credited with five species by FOWLER (of which only two really occur there, *Epinephelus quernus* Seale and *E. taurina* [FORSKAL]), while the remainder of Eastern Oceania has some 22 species belonging to these two genera. For the important genera of tropical snappers *Lutjanus* and *Letherinus*, FOWLER lists 16 species for Eastern Oceania exclusive of Hawaii, which has none. *Lutjanus* is, of course, found not only in the Indo-Pacific faunal region, but in the tropical Atlantic. Hawaii has only two species of sardine-like fishes while the remaining island groups of Eastern Oceania have eight.

If other genera or families of marine inshore fishes are considered, the Hawaiian fauna does not seem so depauperate. FOWLER lists 27 butterfly fishes (Family Chaetodontidae) for Hawaii and 29 for the remainder of Eastern Oceania; 21 surgeon fishes (Family Acanthuridae) for Hawaii and 26 for the remaining area. While, as indicated for the sea basses, these lists may not be exact, they do illustrate that Indo-Pacific fish genera tend to be either incompletely represented in Hawai, if not absent, or to be represented rather well.

A consideration of the life history of a representative of one of the families with a large number of Hawaiian species may be illuminating in this context. The Hawaiian manini (*Acanthurus triostegus sandivichensis*) has a pelagic larval stage persisting for 2½ months (RANDALL, 1956) and in general this situation seems to be true for other acanthurids. The chaetodontids, mullids, and priacanthids, among others, also seem to pass through a pelagic stage early in their life history. Perhaps this feature can be considered as a dispersal mechanism, making it possible for such fishes to survive in the pelagic environment long enough to reach isolated islands.

There are no primary freshwater Hawaiian fishes. The endemic species are gobies which live entirely in fresh water as adults, or euryhaline species, such as *Kuhlia* or *Mugil*. The life history pattern of one of these gobies, *Chonophorus stamineus* (EYDOUX and SOULEYET), has been studied and is of interest in considering how it became a part of the Hawaiian fauna. The adults, which live high in mountain streams, migrate seaward during the period from mid-summer through early fall to spawn. The migration ordinarily coincides with a modest freshet which fills the stream. At the last rapids above the sea, the fish attach their eggs to boulders in the rush of the current. After hatching, the larval gobies are flushed downstream into the sea, where they spend some 6 months before returning to the streams. The larvae, migrating back from salt water, often enter the streams in large numbers. Here again, the period of larval existence in the sea may also be considered as a dispersal mechanism.

5. INTRODUCED SPECIES

The lack of primary freshwater fishes and the relatively depauperate situation obtaining for some large genera of inshore marine fishes may suggest the possibility of favorable environmental niches for some species not naturally found in Hawaii. While not examined by me, a parallel situation for the inshore and freshwater invertebrates may be anticipated. Some of the introductions were motivated by an appreciation of this situation. (See part 3 of table 1.)

The following list of introduced aquatic animals is incomplete. There has been no attempt to catalogue the fortuitous introductions of smaller invertebrates. Exotic aquarium fishes are imported in substantial numbers and in all likelihood some of these fish have become established, but their establishment has not yet been recognized and recorded.

a) *List of Established Introduced Species*

Mollusks:

1. *Venerupis philippinarum* (Adam and Reeve)

Common name: Japanese clam.

First recorded introduction in 1920 of some 10 barrels. The clams were brought from Japan and planted in Pearl Harbor, Kaneohe and Waialae Bay on Oahu. However, this species was reported to have been established on Molokai before 1920. It is presently well established on Oahu, Molokai and Hawaii, and possibly on Maui and Kauai.

2. *Cytherea meretrix* Linnaeus

Common name: Japanese clam.

The first shipment consisting of some 10 gallons of clams was brought in from Japan in 1926. These were planted in Kaneohe Bay and off Kalihi, Oahu. In 1939 a second shipment of 20,000 small seed clams was received from Japan and planted in Kaneohe Bay and Mokapu, Oahu. This species is well established on Oaha and possibly on other islands also.

3. *Crassostrea virginica* (Gmelin)

Common name: Eastern or Chesapeake oyster.

The valuable oyster of eastern North America was first reported to have been imported in 1871; however, the importation was apparently not successful. A shipment of 300 was brought in from San Francisco in 1883 and planted off Kalihi, Oahu. This planting also failed to establish this species. In 1893, 1,000 were brought in from San Francisco and 38,614 in 1895. Both of these shipments were planted at Manana, Ewa, in Pearl Harbor on Oahuand resulted in establishing the species in Pearl Harbor. While there were subsequent shipments they did not apparently contribute to its establishment in Hawaii. In recent years oysters taken from Pearl Harbor have been planted at localities on Kauai, Molokai, Maui, and Hawaii. Although there has been some evidence of successful spawning through the appearance of spat, these plantings are too recent to afford a basis for judging their success.

Crustacea:

4. *Procambarus clarkii* (Girard)

Common name: Crayfish.

The occurrence of this species in Hawaii is the result of erroneous identification. Another crayfish, *Pacifastacus leniusculus* (Dana), was reported as being introduced from California in 1923 and again in 1927. In 1937 and 1939 a total of 3,225 crayfish were distributed to various localities on Hawai and Kauai. The crayfish were taken from a taro patch at Ahumanu, Oahu, where they had been earlier established.

The species introduced at Ahumanu was reported to be *Pacifastacus nigrescens* (STIMPSON). However, the only species of crayfish currently found in Hawaii is the Louisiana crayfish, *Procambarus clarkii.* So far as the records show crayfish were brought in from either California or possibly Oregon, and it is likely that the introduced *Procambarus* was collected rather than the native *Astacus.* Presently the Louisiana crayfish is abundant on all the major islands and is considered a pest in taro patches from its habit of burrowing through dikes allowing the escape of water used to irrigate the taro.

5. *Scylla serrata* (FORSKAL)

Common name: Samoan Crab.

This large crab has a wide distribution from Africa and India through tropical Asia and Polynesia. The normal habitat is saltwater swamps and mangrove areas. Beginning in 1926 a few crabs were brought in each year from Samoa until by 1935. the last year of any introductions, a total of 98 crabs had been released in Hawaiian waters. The largest number brought in during a single year was 23 (introduced in 1932) and aside from the introductions during 1932, which was on the Hilo coast of Hawaiii, all the introductions were at various localities on the island of Oahu. Today this crab is common in the waters of all the major islands of Hawaii. It is valued as food and brings a good price in the local markets.

Fish:

6. *Harengula vittata* (CUVIER & VALENCIENNES)

Common name: Marquesan sardine.

The Marquesan sardine is the first species of a purely marine fish established in Hawaiian waters by transplantation. An account of the introduction of this species is given by MURPHY (1960). The initial introduction from the Marquesas Islands was made in December of 1955 when some 7,500 fish were released off Barbers Point, Oahu. There was a single introduction of 7,900 fish in the fall of 1956 and two large lots of 24,000 and 32,000 in March and December of 1957. A large introduction of 56,000 was made in February of 1958, followed by two smaller plantings of 9,400 and 3,000 in May and June. The last planting of 4,000 was made in March of 1959. All releases of this species were made at various localities around the island of Oahu.

Although as early as the fall of 1956 recoveries of small numbers of Marquesan sardines were made, beginning in the late summer of 1958, some of the fish recovered were too small in size to be derived from any of the original introductions. Additionally, up to this time, all recoveries were from Oahu; many of these later recoveries of small fish were from Kauai, Maui and Hawaii. The large plantings made in 1957 and early in 1958 may have provided a sufficient stock of fish to establish the species. The recoveries which could be attributed to the small plantings of 1955 and 1956 were few and of such a size to suggest that they were all a portion of the original releases.

7. *Dorosoma petenense* (GUNTHER)

Common name: Threadfin shad.

The threadfin shad was first introduced in 1958. A small stock secured from the Chino Fish Station of the California Department of Fish and Game was flown to Hawaii and released in a hatchery pond at Nuuanu, Oahu. Subsequently some

53 of these fish were released in the quarry pond on the campus of the University of Hawaii.

Following this introduction, a large number of fish were brought to Hawaii from the Puddingstone Reservoir near Chino, California; however, these fish were used in sea tests of this species as livebait for tuna fishing. Another large introduction of some 3,000 fish was again made in August, 1959, from Puddingstone Reservoir and these fish were released in various localities on Kauai, Oahu, and Maui.

8. *Salmo gairdneri* RICHARDSON

Common name: Rainbow trout.

This species has been repeatedly introduced to all islands. From 1920 to 1959 about 270,000 trout fry, hatched from eyed eggs brought in from California, Oregon and Washington, have been released in various island streams. While a permanent breeding population of rainbow trout occurs in the streams of the Kokee area of Kauai, the needs of the sport fisheries cannot be met by the reproductive rate of the Kokee fish, and it is therefore supplemented by stocking from imported eggs.

9. *Cyprinus carpio* LINNAEUS

Common name: Carp

The carp was introduced prior to 1900 and is found today on all major islands, generally in impoundments.

10. *Carassius auratus* (LINNAEUS)

Common name: Goldfish

This species was established here before 1900 and occurs on all major islands. There has doubtless been many reintroductions.

11. *Barbus semifasciolatus* GUNTHER

Common name: Half-banded barb

This species is an exotic aquarium fish which was released in Nuuanu Reservoir 3 on Oahu. It can be considered as established in Hawaii, but its establishment is precarious as the drainage of the reservoir would probably remove it from the Hawaiian fauna.

12. *Misgurnus anguillicaudatus* (CANTOR)

Common name: Dojo

The dojo was established on Kauai, Oahu and Maui before 1900. It is found in many localities on those islands; its use as bait for fishing being apparently instrumental in its spread.

13. *Clarias fuscus* (LACEPEDE)

Common name: Oopu kui

The Asiatic catfish was established in the waters of Kauai, Oahu, and Maui prior to 1900. It is a common fish.

14. *Gambusia affinis* (BAIRD and GIRARD)

Common name: Mosquito fish

This, and several other species, were brought to Hawaii from Seabrook, Texas, in 1905 for mosquito control. An account is given of the introduction of *G. affinis*, *Mollienesia latipinna* and *Fundulus grandis* by VAN DINE (1907). The initial stocking was at Moanalua, Oahu, and young fish from this locality were subsequently introduced into the fresh waters of all the islands. This species is most abundant in the lower portions of streams, while *Lebistes reticulatus* is abundant in the middle reaches.

15. *Mollienesia latipinna* LE SUEUR

Common name: Sailfin

The sailfin was introduced in 1905 from Seabrook, Texas, and established initially at Moanalua, Oahu. A second introduction was made in 1940 to the Nuuanu Reservoir on Oahu; this stock was largely of the black cultivated variety. In 1950, 21 pounds of sailfins were taken from Kapalama Canal, Oahu, to Port Allen and Nawiliwili, Kauai, but apparently did not survive. The Seabrook, Texas, stock is well established in brackish water areas of Oahu and Molokai.

16. *Limia vittata* (GUICHENOT)

Common name: Top minnow

Limia vittata is found in the streams flowing through Honolulu which include Moanalua, Kapalama Canal, Nuuanu, and Manoa streams. It is found in the lower portions of the streams and in salt water. The origin and date of introduction are not known.

17. *Lebistes reticulatus* (PETERS)

Common name: Guppy

The guppy was introduced in 1922 and established in streams flowing through Honolulu and into Kaneohe Bay as well as some others on the windward side of Oahu.

18. *Xiphophorus maculatus* GUNTHER

Common name: Moonfish

This species was introduced in 1922 on Oahu and again in 1940 in the Nuuanu Reservoir, Oahu. The species has been taken in some irrigation reservoirs on Maui; the date and manner of introduction of the fish there are not known.

19. *Xiphophorus hellerii* HECKEL

Common name: Swordtail

First introduced into the streams around Honolulu and Kaneohe Bay, Oahu, in 1922. Nuuanu Reservoir was stocked in 1940 and many of the leeward streams on Kauai were stocked, but with, in some instances, the red hybrid swordtail type. The dates of these plants are not known.

20. *Micropterus salmoides* (LACEPEDE)

Common name: Largemouth bass

Largemouth bass were first brought to Hawaii in 1897 from California. Only 21 fish survived the trip to Hilo, where they were released in the Wailuku River which flows through that city. This species does not occur today in the Wailuku River, but is well established in the Waiakea mill pond in Hilo, which is spring fed, and in the large stream flowing from it. A shipment from California to Oahu in 1908 was released in the Wahiawa reservoir which established the species there. In 1911 some 300 largemouth bass were brought to Kauai from California and released in Waiuli reservoir and Koloko reservoir. The species is well established today on all major islands.

21. *Micropterus dolomieu* LACEPEDE

Common name: Smallmouth bass

Seventy-four smallmouth bass were initially brought from Elk Grove Hatchery in California to Oahu in 1953. For a time these fish were at the Fish and Game Laboratory in Honolulu, and subsequently the survivors were released in a lily pond near the Nuuanu Reservoir where they spawned. Some of the original stock, together with offspring, were released in Nuuanu Reservoir and by 1956 were well established there. In May of that year a shipment of 1200 small fish were received from the Elk Grove Hatchery of the California Department of Fish and Game. Beginning in 1956 smallmouth bass were planted in both forks of the Waialua River on Kauai, in Kaukonahua Stream above Wahiawa Reservoir on Oahu and, by 1958, in Puakea Reservoir on Hawaii. The bulk of the stock for these plants came from Nuuanu Reservoir with some additions from the large 1956 shipment. The species is established on Kauai and Oahu and possibly on Hawaii.

22. *Lepomis macrochirus* RAFINESQUE

Common name: Bluegill

Fourteen fish were brought from California in 1946 and established in a private lily pond near Kaneohe Bay, Oahu. The bluegills reproduced in this pond and young were thereafter stocked in suitable places on all major islands. This species is well established in the Hawaiian Islands.

23. *Cichlasoma meeki* (BRIND)

Common name: Firemouth

Established in Nuuanu Reservoir by a release in 1940. Reported to occur also in a drainage canal in the McCully district of Honolulu.

24. *Astronotus ocellatus* (AGASSIZ)

Common name: Oscar

A small stock of this species was obtained from the Steinhart Aquarium in San Francisco and was successfully bred in tanks at the Fish and Game Laboratory. Sixty-four young, a portion of a brood, were released in Nuuanu Reservoir 2. Subsequently young fish, offspring of some of the 64 originally introduced, were taken from this reservoir and stocked in Wahiawa Reservoir on Oahu and Waialua Reservoir on Kauai. These last plants are too recent (1958) to judge their success.

25. *Tilapia mossambica* (PETERS)

Common name: Tilapia

In 1951 some 60 small *Tilapia* were sent to Honolulu from Singapore. Of the original shipment, all but 14 subsequently became diseased and died. The 14 survivors bred in the laboratory tanks of the Fish and Game Division and the resultant offspring were used for stocking purposes. This species has been useful for four purposes in Hawaii: (1) as live bait for tuna fishing; (2) as a means of controlling certain aquatic plants in irrigation systems; (3) as a food fish — modest quantities are sold in local markets; and (4) for sport fishing — tilapia provides good fishing especially for youngsters. It is well established on all of the major Hawaiian Islands.

26. *Tilapia macrochir* (BOULENGER)

Common name: Tilapia

Tilapia macrochir was first introduced in 1957, from Leopoldville, Belgian Congo, bya shipment of 52 fish 4 to 5 centimeters in length. Beginning in 1958 this species was stocked out, using offspring obtained from the original stock in the Fish and Game Laboratory tanks, in Wahiawa Reservoir. Additional plantings were made in Wahiawa Reservoir in 1959 until a total of 1,279 fish, 5 to 8 centimeters long, were released. During 1959, 150 fish were also released on Maui.

27. *Tilapia zillii* GERVAIS

Common name: Tilapia

A shipment of *T. zillii*, numbering 19 fish, was received from Antigua, B. E. I. in 1955. These fish were held and bred in the Fish and Game Laboratory tanks until 1957 when 1,500 fish were released in plantation reservoirs on Maui. Plantings were made in 1958 and 1959 in reservoirs on Hawaii and Oahu. *Tilapia zillii*, where stocked in a weed-filled reservoir, has done, in some instances, a remarkable job of removing aquatic vegetation. Often where some domestic use is made of the water, chemical methods of control are not practical and in any case these methods must be continuous.

28. *Tilapia melanopleura* DUMERIL

Common name: Tilapia

Tilapia melanopleura was obtained from Leopoldville, Belgian Congo, in 1956 in a single shipment of 50 fish. After breeding fish in the Fish and Game Laboratory tanks, releases of young were made on Kauai in 1957 and 1958. A total of 1,673 fish were released in a drainage canal and reservoir at Kekaha, Kauai. These introductions were made for the purpose of controlling aquatic vegetation too coarse for *T. mossambica*.

29. *Ophiocephalus striatus* BLOCH

Common name: Snakehead

The snakehead is another species of oriental origin that was established on Oahu prior to 1900. It is not uncommon.

30. *Fluta alba* (ZUIEW)

Common name: Ricefield eel

The ricefield eel was established on Oahu before 1900. It is common but secretive, and is occasionally dug out of old taro fields alive long after the field has been drained.

b) *Supplemental List 1,*
Species That May Be Established

Many of the species listed here can be taken or seen in a wild state; however, their introduction is recent and there is no clear-cut evidence of successful reproduction and the ocurrence of young. It is likely that some of the species in this list will become established and others will not.

Mollusks:

1. *Haliotis cracherodii* LEACH

Common name: Black abalone

The first introduction of this species, which has a more southerly range than the other abalones of California, was in 1927 and 1928 when a total of 35 was brought in from California. Some of these may have been the red abalone *Haliotis rufescens*. There was no evidence of survival.

In 1958, 167 black abalones from California were planted off Rabbit Island, Oahu. There was some evidence of poaching found when later checking on the success of this planting. In August of 1959 and again in September of that year a total of 728 black abalones were planted off Pyramid Rock, Oahu. In a check of the first Pyramid Rock planting subsequently, some 19 abalones were found moribund and some 20 apparently in excellent shape. The survivors seemed to be those which were able to find adequate shelter. These were small abalones 2.5 to 7.5 centimeters in shell diameter and were from southern or Lower California.

Crustacea:

2. *Macrobrachium lar* (FABRICIUS)

Common name: Giant freshwater shrimp

Some 340 shrimp were brought to Honolulu from Guam in 1956. Shortly after, 94 were released in Pelekunu Stream on windward Molokai and the remainder held in the Nuuanu hatchery pond of the Fish and Game Division. In 1957, some 27 shrimp were released in Nuuanu Stream on Oahu. Some of the remaining shrimp held at the hatchery spawned and the eggs hatched but there was no evidence of survival of young. It is possible that the larvae of this species require a sojourn in salt water.

Fish:

3. *Ictalurus punctatus* (RAFINESQUE)

Common name: Channel catfish

The channel catfish was first introduced in 1953 and again in 1954 from California. A total of 38 fish were received and were held for 5 years at the Nuuanu hatchery in an attempt to propagate the species. This attempt was not successful and some of the mature fish were lost through the use of hormone injections to induce spawning. In 1958, 1,715 young, brought in from Fort Worth, Texas, were released in Wahiawa Reservoir, Oahu. Another planting of 4,500 was made in Wahiawa Reservoir in 1959 as well as one of 1,300 in the Waialua River on Kauai. These fish were shipped in from a hatchery in Oklahama. A few catfish have been taken in Wahiawa Reservoir indicating both survival of the original planting and excellent growth of the fish.

4. *Kuhlia rupestris* (LACEPEDE)

Common name: Nato

A shipment of 43 *K. rupestris* was received from Guam in 1957 and held in Fish and Game Laboratory tanks. In 1958 another shipment of 170 was received and 104 of this shipment were subsequently planted in a small stream at Bellows Field, Oahu.

5. *Cephalopholis argus* (BLOCH and SCHNEIDER)

Common name: Roi

In 1956, 571 were brought to Hawaii from Moorea, Society Islands. These fish were given a prophylactic treatment of copper sulphate for 5 days and then planted in two lots: 171 off Browns Camp, Oahu, and 400 off Keahole Point, Hawaii. Underwater photographs of roi were obtained off Browns Camp in 80 feet of water during the summer 1958, and the Hawaii planting was investigated in the fall of 1958 where 11 fish were sighted, including a small one of 15 cm. which suggests that some reproduction had occurred. The fish deemed to be from the original plantings had evidently grown since no fish longer than 30 centimeters were brought to Hawaii while many of those sighted in 1958 were estimated to be 45 cm. or more in length.

6. *Cephalopholis urodelus* Bloch and SCHNEIDER)

Common name: Rero

Eight *C. urodelus* were released off Browns Camp, Oahu, in 1958. These fish were part of a shipment from the Marquesas Islands.

7. *Epinephelus merra* BLOCH

Common name: Tarao

Plantings of this species were made in 1956 at Wainini, Kauai, and Kaneohe Bay, Oahu, where 132 were released at the first-named locality and 469 at the second. The fish came from Moorea, Society Islands.

8. *Epinephelus spiniger* (GUNTHER)

Common name: Not known

Some 22 *E. spiniger*, brought from the Marquesas Islands in 1958, were released at Browns Camp, Oahu.

9. *Epinephelus fasciatus* (FORSKAL)

Common name: Matapuu

This species was brought from the Marquesas Islands in 1958, and 51 fish were released off Browns Camp, Oahu.

10. *Epinephelus hexagonatus* (BLOCH and SCHNEIDER)

Common name: Tarao a'au

Some 113 *E. hexagonatus* were released off Keoneoio, Maui, in 1956. The fish were brought from Moorea, Society Islands.

11. *Lutjanus gibbus* (FORSKAL)

Common name: Tuhara

L. gibbus was brought in from the Marquesas Islands in 1958, and released in Kaneohe Bay, Oahu. There were 40 fish in this release.

12. *Lutjanus kasmira* (FORSKAL)

Common name: Taape, Blue-lined snapper

Five *L. kasmira* were brought from the Marquesas Islands in 1955 and held in captivity at Coconut Island, Kaneohe Bay, Oahu. In 1958, 2,435 *L. kasmira* were released in Kaneohe Bay from a shipment originating in the Marquesas Islands.

13. *Lutjanus vaigiensis* (Quoy and Gaimard)

Common name: Toau

The first shipment of 40 *L. vaigiensis* to Hawaii came from the Marquesas Islands in 1955. These fish were held captive at Coconut Islands. I 1956, 239 *L. vaigiensis* from Moorea, Society Islands were released in Kaneohe Bay, Oahu. In 1958, 23 additional *L. vaigiensis* from the Marquesas Islands were released in Kaneohe Bay.

14. *Lutjanus guttatus* (Steindachner)

Common name: Spotted Rose Snapper

In May 1960, an estimated 3,000 spotted rose snappers were released in the lee of Ilio Point, Molokai, and 400 more in Kewalo Basin, Oahu. These snappers were collected off Manzanillo, Mexico, during the spring of 1960 and brought to Hawaii in the bait tanks of the M. V. Charles H. Gilbert, a research vessel of the Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service.

c) *Supplemental List 2,*

Introduced Species Which Probably did not Survive

Mollusks:

1. *Ostrea lurida* Carpenter

Common name: California oyster

This species was brought from San Francisco to Manana, Oahu, in 1893. There were some 3,000 oysters in the shipment.

2. *Crassostrea gigas* (Thunberg)

Common name: Japanese oyster

A small shipment of unknown size from Japan was planted at Kalihi, Oahu, in 1926. Another shipment of 2,500 was planted at Pearl Harbor and Mokapu, Oahu, in 1938, and in 1939 a large shipment of seed oysters, some 2,150,000, were set out at Coconut Island and Mokapu in Kaneohe Bay, Oahu.

3. *Crassostrea amasa* (Iredale)

Common name: Coral rock oyster

A sack of this species, 75 pounds in weight, was shipped from Australia in 1956. The oysters were established in Coconut Island ponds where they seemed to do quite well, and some were still living in 1959, but there was no evidence of reproduction.

4. *Crassostrea commercialis* (Iredale and Roughley)

Common name: Australian oyster

There were two importations of this species, one of 3 bushels in 1928 and another of 24 bushels in 1929. The shipments were from Port Stephens, New South Wales, Australia and were planted at various localities on Oahu, including Mokapu.

5. *Pinctada martensii* (DUNKER)

Common name: Japanese pearl oyster

A small shipment was made in 1956 from Japan and placed in a holding area in the Kewalo Basin channel, Oahu.

6. *Tevela stultorum* (MAWE)

Common name: Pismo clam

Two shipments of 218 pismo clams were made in 1927 and 1928 from California. They were stocked out at Kahana and Kailua, Oahu.

7. *Tridacna crosea* LAMARCK

Common name: Giant clam

Sixty *T. crosea* were brought from Rose Island in 1951 and established in holding ponds at Coconut Island. A few of these clams were alive in 1959 but there was no evidence of reproduction.

Fish:

8. *Anchoa compressa* (GIRARD)

Common name: California anchovy

A release of 6,000 *A. compressa* was made in Kaneohe Bay, Oahu, in 1932. The fish were part of a load of live bait aboard a tuna clipper from California.

9. *Salmo trutta* LINNAEUS

Common name: Brown trout

This species was released in various localities on Kauai in 1935. Some 24,000 fry were planted from eggs presumably brought to Hawaii from one of the Pacific states. A large dead brown trout was found after a freshet in the Wainiha Stream on Kauai in 1949, indicating survival in that stream to that date, at least.

10. *Salvelinus fontinalis* (MITCHELL)

Common name: Brook trout

Three plantings of this species in Hawaii have been made. For the first, in 1876, from the California Fish Commission, we have no record concerning either the number or the places stocked. A second planting of 1,000 at Waimea, Kauai, was made in 1894, and a third of 12 fish at Wailuku, Hawaii in 1896. Fish for these last two plantings were also from the California Fish Commission.

11. *Plecoglossus altivelis* TEMMINCK and SCHLEGEL

Common name: Ayu

In 1925, 250,000 ayu were planted in various localities on Kauai, Oahu and Hawaii. The shipment came from Japan.

13. *Oncorhynchus tschawytcha* (WALBAUM)

Common name: King salmon

A shipment of unknown size of this species was made to Hawaii from the California Fish Commission in 1876. The release localities were not known. In 1925 and 1927, 66,000 king salmon fry were released on Kauai at various localities.

13. *Ictalurus nebulosus* (Le Sueur)
Common name: Brown bullhead

Reported to have been released near Hilo, Hawaii in 1893. The origin of the shipment and the number released is not known.

14. *Fundulus grandis* (Baird and Girard)
Common name: Killifish

An unknown number was brought from Seabrook, Texas in 1905 and released at Moanalua, Oahu.

15. *Oryzias latipes* (Schlegel)
Common name: Medaka

Reported to have been stocked in unknown numbers on Oahu in 1922.

16. *Roccus saxatilis* (Walbaum)
Common name: Striped bass

An unknown number of striped bass was brought to Hawaii from San Francisco Bay, California in 1922. Releases were made at a number of localities on Kauai.

17. *Trichogaster leeri* (Bleeker)
Common name: Pearl gorami

A few pearl gorami were released in Nuuanu Reservoir, Oahu in 1940. They have never been taken since.

18. *Osphronemus goramy* Lacepede
Common name: Giant gorami

In 1950, 9 small giant gorami were brought to Hawaii from the Philippines. Some of these survived for a long time, but did not reproduce. There may have been earlier unsuccessful introductions.

6. DISCUSSION

Listed in Table 1, by habitat, are the introduced species. This list is divided into three major parts: (1) established species, (2) species that did not become established, and (3) species introduced too recently to permit grouping in either of these two categories.

Of the species successfully established, one is a marine fish of open water, four are primarily estuarine, 19 are primarily pond dwelling and five are species found in streams. Of course, some of these species are found in more than a single habitat.

The introduction of species into the Hawaiian marine environment has been only attempted on a reasonable scale since 1956, and many of the marine introductions made since that date seem to be surviving but evidence of reproduction is lacking. It is not unlikely that the number of individuals introduced may be crucial in determining the success of establishing a new species, especially in a marine environment. The history of the establishment of the Marquesan sardine in Hawaii suggests that those releases of fish with 20,000 or more individuals were important in the establishment of this species while those of 10,000 or less were not.

Table 1

Species	Open Sea	Reef	Estuary	Pond	Stream
(1) Established Species					
Venerupus philippinarum			×		
Cytherea meretrix			×		
Crassostrea virginica			×		
Procambarus clarkii				×	×
Scylla serrata			×		
Harengula vittata	×		×		
Salmo gairdneri					×
Cyprinus carpio				×	
Carassius auratus				×	
Barbus semifasciolatus				×	
Misgurnus anguillicaudatus				×	×
Clarias fuscus				×	×
Gambusia affinis				×	×
Mollienesia latipinna			×	×	
Limia vittata			×	×	×
Lebistes reticulatus				×	×
Xiphophorus maculatus				×	
Xiphophorus hellerii				×	×
Micropterus salmoides				×	
Micropterus dolomieu				×	×
Lepomis macrochirus				×	
Cichlasoma meeki				×	
Astronotus ocellatus				×	
Tilapia mossambica			×	×	
Tilapia macrochir				×	
Tilapia zillii				×	
Tilapia melanopleura				×	
Ophiocephalus striatus				×	
Fluta alba				×	
Did Not Establish					
Ostrea lurida			×		
Crassostrea gigas			×		
Crassostrea amasa		×			
Crassostrea commercialis			×		
Pinctada martensii			×		
Tivela stultorum		×1)			
Tridacna crosea		×			
Anchoa compressa	×		×		
Salmo trutta					×
Salvelinus fontinalis					×
Plecoglossus altivelis					×
Oncorhynchus tschawytcha	×				×
Ictalurus nebulosus				×	
Fundulus grandis				×	
Oryzias latipes				×	
Roccus saxatilis	×		×		
Trichogaster leeri				×	
Osphronemus goramy				×	

Table 1 — continued

Species	Open Sea	Reef	Estuary	Pond	Stream
Introduced Species That May Become Established					
Haliotis cracherodii		×			
Macrobrachium lar				×	
Ictalurus punctatus				×	
Kuhlia rupestris			×		×
Cephalopholis argus		×			
Cephalopholis urodelus		×			
Epinephelus merra		×			
Epinephelus hexagonatus		×			
Epinephelus spiniger		×			
Epinephelus fasciatus		×			
Lutjanus gibbus		×			
Lutjanus kasmira		×			
Lutjanus vaigiensis		×			
Lutjanus guttatus		×			

[1] Sand beaches.

The successful estuarine introduction were three mollusks and a crab. While not much can be concluded from the successful introduction of the mollusks — in contrast to those species which failed to become established — the success in establishing the Samoan crab in view of the few individuals introduced seems remarkable. However, some of the estuarine areas where this species was released have a low rate of tidal flushing, a situation which may be conductive to the rapid growth of a population within the estuarine area.

The pond habitat in Hawaii is essentially artificial, being primarily irrigation reservoirs. There are no indigenous species with ponds as a primary habitat. Since most reservoirs, especially irrigation reservoirs are drainable, this is a precarious habitat. Nevertheless, the pond habitat has the greatest number of successful introductions, some 19 in all. Some of the lower portions of the larger streams contain deep areas which are suitable for pond species that can also resist freshets which occasionally but inevitably occur. Both *Clarius fuscus* and *Misgurnus anguillicaudatus* are found in this habitat.

In general, Hawaiian streams are small, rapidly flowing brooks, torrential in their upper reaches. The native freshwater species of fish are dependent upon free access to the sea primarily to complete their reproductive cycle. In the development of some of the major irrigation systems, canals were channeled along the contours of the mountains at elevations above the highest sugar canefields and the stream water for each of the crossing streams diverted into the canal. Such diversions seriously reduced stream flows in the lower reaches especially during periods of low water and apparently reduced the population of gobies that normally reside in the upper parts of the stream but must descend to the lowest part to spawn. The invasion of exotic fishes, aside from trout, was, insofar as streams are concerned, primarily in the lower and middle reaches and here the possibility existed that the goby fry, migrating in from the sea, would be exposed to predation by those exotics. Of course, there are other predators, perhaps more serious, such as man, but in any case abundant stocks of native stream fishes are to be found in remote windward streams of great difficulty of access, and without irrigation diversions or populations of exotic fishes, such as Pelekuna Stream on Molokai.

Whether or not trout introductions had any major effect on native freshwater fish is difficult to evaluate, but areas where trout thrive, such as the Kokee area of Kauai, water temperatures are perhaps lower than that which is optimum for native stream fishes. Ordinarily, streams above elevations of 800 meters seem to lack native fishes.

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Vernon E. Brock
Director, Hawaii Area,
Bureau of Commercial Fisheries
P. O. Box 3830, Honolulu, Hawaii.

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VERNON E. BROCK
and ROBERT H. RIFFENBURGH

FISH SCHOOLING: A POSSIBLE FACTOR IN REDUCING PREDATION

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Fish Schooling:
A Possible Factor in Reducing Predation

By

Vernon E. Brock and Robert H. Riffenburgh*

Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii

Introduction

The schooling of fishes has long attracted attention, and a number of workers have studied fish schools and the behaviour pattern of the fish to gain some understanding of the nature of the factors responsible for schooling.

PARR (1927) described the schooling behaviour of chub mackerel and killifishes in aquaria and concludes that the behaviour observed is a visual response to other individuals of the same species. BREDER and HALPERN (1946) found that blinded goldfish do not school, and BREDER (1951) in his study of schooling in *Jenkinsia* states that schooling will not occur in darkness or with blinded fish for some ten species which have been tested by various authors. KEENLEYSIDE (1955) found that blinded fish did not school effectively but there was evidence that the blinded fish could detect others, possibly through smell. SPRINGER (1957) concluded that his observations of a school of *Jenkinsia* "make untenable the view that individual fish of this school maintained contact with one another solely by visual means". BREDER (1954) developed equations descriptive of the forces in schooling.

In general, the concern of the authors briefly reviewed above was with the internal factors responsible for schooling, and the school was considered largely as an isolated phenomenon. However, BREDER and HALPERN briefly discuss the possibility that schooling may confer some protection from predation and indicate some of the difficulties which must be considered, but the matter is not developed quantitatively. SPRINGER described a school which resembled an unknown large creature as an example of "collective mimicry" and was, in the authors' opinion, protected by its frightening appearance. WELTY (1934) experimented with the effects of grouping fishes on learning, and found that, except for mudminnows, grouped fishes learned faster, retained longer, and ate more than did isolated fishes of the same species. The grouped fishes tended to respond as a unit, a mixture of fishes with two different responses to the same stimulus responded more slowly than did a group trained to give a single uniform response to the stimulus, an effect which WELTY labelled group cohesion.

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* Also on mathematics faculty, University of Hawaii, Honolulu.

Species of fish that ordinarily school and school strongly seem to have two characteristics in common: (1) they are open water species whose immediate environment offers little in the way of shelter and (2) they are not climax predators, at the end of a food chain, but are prey species at least for a substantial portion of their life history. Likewise, the predators at the end of a food chain are ordinarily non-schooling, solitary fish.

This aspect of the predator-prey relationship suggests that schooling may confer some protection against predation and that for perhaps similar reasons predators function more effectively if solitary.

The schooling of some predatory species such as the tunas does not necessarily constitute contrary evidence. There is evidence that for much of the life span of these species, they are prey species, and when they do attain sizes sufficient to render them largely immune from predation, the schools formed are smaller and less stable than is true for younger and smaller fish of the same species. SETTE (1950) suggests that schooling of predators may assist in the capture of prey. His discussion of the reasons for such an advantage would seem to apply after the prey was located. If the relationships suggested in this paper between predator and prey be true, it would seem that schooling by a predator may, under some conditions, reduce the efficiency of scouting for prey.

If schooling does provide some protection against predation, this may occur simply because scattered prey will be detected more frequently by a predator than would be true of the same number of prey bunched into a school. While the true measure of the validity of this concept must depend upon observations and measurements in the field, certain relationships which seem essentially reasonable, make it seem likely that schooling is, in one common aspect, a mechanism of protection against predation. This aspect of schooling will be discussed with the assumption that the means of detection employed by the predator is visual. Other means of detecting prey are, of course, possible; their use would not change the conclusions reached on the basis of a visual model unless detection is independent of distance.

Consider schooling as a protective device; there are two factors operating at cross purposes: if a single fish is regarded as a group of size one, schooling (a) reduces the number of groups and consequently the frequency of encounter with predators; we shall call this encounter advantage; (b) increases the size of groups, thus increasing the chance of detection; we shall call the advantage here lost a detection advantage. A third factor which may give an advantage from schooling is the limitation of capacity of the predator. If a predator sights a large school of prey, he will eat to capacity, possibly leaving alive most of the school, and will reduce his searching activity to a negligible amount for some time thereafter. We shall call this advantage due to the predator's limited capacity a capacity advantage.

Development of Method

We shall develop probabilities for advantages of schooling on the basis of mathematical models relating to the above events. We shall consider in this paper only non-schooled predators; if predators school, they overlap each other's sight ranges, reducing the volume of ocean scouted and hence reducing scouting efficiency. Schooling of predators would be advantageous to the predators only in the special case in which their prey are schooled and cannot be seen at full sight range; here a predator could see another predator engaging in feeding activity when he could not see the prey being consumed. A consideration of the optical peculiarities of water is pertinent in this connexion. The distance which an object of given size can be seen depends upon two factors: the intercept angle at the eye and the contrast difference between the object and the background. Due to backscatter and light absorption an object of the highest contrast will fade from sight regardless of size at a relatively small distance, say 200 feet or less, even in the clearest water. This means that for objects above a fairly modest size, large enough to give an intercept angle adequate for effective vision at the distance where light absorption and backscatter reduce contrast difference to the point of invisibility, taken at 2 per cent. for man (DUNTLEY, 1952), any increase in the size of the object will not effectively increase the distance which it may be seen. The critical intercept angle for the human eye is taken as one minute which would occur for an object 0·72 inches in diameter at 200 feet.

Consequently the observation of feeding behaviour of a predator by another as a means of locating food would be effective only for rather small prey; the greater the reduction of sight range by contrast loss, the smaller the prey.

In supposing that schooling is of advantage to prey, we shall give predators every advantage, hence the first two assumptions given below. But predation will be assumed effective only during daylight hours.

Definitions:

(1) n_p represents the number of predators.
(2) n_f represents the number of prey (f for food fish).
(3) n_e represents the number of schooled prey a predator can hold at one eating.
(4) r represents the distance at which a predator can see its prey.
(5) r' represents the radius of a school of prey (assumed to be approximately spherical).
(6) d_{ik} represents the distance between the ith prey and the kth predator, $i = 1, 2, \ldots, n_f$, $k = 1, 2, \ldots, n_p$.
(7) $d_{k'}$, represents the smallest d_{ik} for any k, i. e. $\min(d_{ik})$, $k = 1, 2, \ldots, n_p$.

Assumptions:

(8) If a predator is in sight of a prey, he will sight it.
(9) If a predator sights a single prey, he will eat it.
(10) The average distance between predators and between non-schooled prey is greater than r.
(11) Predators and prey move randomly.
(12) The concentrations of predators and prey are constant.
(13) If schooling occurs, all members are schooled and schooled in a single school. (It will be seen later that this assumption may be relaxed.)

d_{ik} are random continous variables, and therefore so are $d_{k'}$. Whenever $d_{ik} > r$, the ith prey remains alive; thus whenever $d_{ik} \leq r$, the ith prey is eaten. Let us denote by $P[d_{ik} \leq r]$ the probability that the ith prey is sighted (and therefore eaten) by the kth predator.

Since the d_{ik} are random for all i and all k and the initial positions of all fish at daybreak are random,

(14) $P[d_{ik} \leq r] = P[d_{jl} \leq r],\ i, j = 1, 2, \ldots, n_f;\ k, l = 1, 2, \ldots, n_p.$

Hence the expected number of non-schooled forage fish which will be eaten is $n_f n_p P[d_{ik} \leq r] \equiv E_1$.

In the case of schooled fish, the probability that the kth predator will sight the school will be $P[d_{k'} \leq r]$, $k = 1, 2, \ldots, n_p$. Since d_{ik} are random for all k and inital positions of predators at daybreak are random,

(15) $P[d_{k'} \leq r] = P[d_{l'} \leq r],\ k, l = 1, 2, \ldots, n_p.$

Hence the expected number of schooled prey which will be eaten is $n_e n_p P[d_{k'} \leq r] \equiv E_2$.

It follows that whenever schooling is advantageous to the prey,

(16) $$E_2 < E_1,$$

or, upon substituting, rearranging, and cancelling,

(17) $$\frac{n_e}{n_f} < \frac{P[d_{ik} \leq r]}{P[d_{k'} \leq r]}$$

since all components are non-negative.

At this point a few comments are in order. It should be clearly recognized that the primary variable (d_{ik}) being considered is distance and is the distance between two particular, randomly placed fish; it does not involve a number of fish in any sense. It would be possible to consider the number of prey within sight of the predator at any time, which would be a discrete variable having a poisson distribution with parameter the expected number of prey in an ocean volume the size of the predator's sight sphere, viz. $\mu \frac{4}{3} \pi r^3$, where μ is a density parameter. An inequality analogous to (16) could be set up for the probabilities that exactly zero prey are in sight and the resulting exponentials could be easily simplified. However, this approach is density dependent, is time dependent, and makes the assumption of uniform distribution of fish throughout the ocean.

The approach taken in this paper, by isolating in the expectations of (16) the components which deal with the distribution of distance between two particular fish, has definite advantages. From the definitions and (14) and (15) it can be seen that we are concerned with the probability distribution of a single d_{ik} or $d_{k'}$, where i, k may take on any admissible values, for a fixed point in time with fixed n_p, n_f. Thus the probability distributions for d_{ik}, $d_{k'}$ are not dependent upon the density of predators or prey in the given ocean space. Also, the probability distribution of distance between two fish is the same for any one time as for any other, and so is independent of time as well as density. (This may be said more rigorously as the distance between two randomly placed fish is orthogonal to time so that the probability distribution of distance is the marginal distribution with respect to distance obtained from the joint distribution with respect to distance and time.) Furthermore, the unjustified assumption of uniform distribution of fish is not made.

The probability distribution for d_{ik} must now be considered. It is well known that even non-schooled fish are contagiously distributed, although the cause, perhaps oceanographic conditions, perhaps food concentrations, is unknown. Thus non-schooled fish may be thought of as uniformly distributed for only small regions of ocean. Within such a region, the probability that there will be a second fish at some distance from a first fish increases as a power function. As the region considered exceeds the contagion region, however, the density of fish becomes less, so that the probability of a second fish at some distance from a first fish will decrease again as the distance becomes great. It is obvious that the derivative (rate of change of distance) must exist for all distances. Thus our curve is smooth in the vicinity of the maximum and must be some sort of bell-shaped curve. The functional form of this curve is unknown. However, we are dealing with a comparison of probabilities at the extreme left of the curve, i. e., from zero to at most $r + r'$, which may reasonably be restricted to the order of a few hundred feet or less. Now for any stable ecological system, the predator will not be very frequently in sight of prey, and thus $E(d_{ik})$ is considerably larger than either or the sum of r, r'. If $E(d_{ik})$ were not much larger than either or the sum of r, r', the predator would encounter the prey often and would eat the prey rapidly and reproduce rapidly. The number of prey would soon reduce to a number implying fewer encounters, which in turn implies an $E(d_{ik})$ much larger than either or the sum of r, r'.

We may now assume that the predator and prey relationship is stable or but slowly changing and thus that we are dealing with the extreme left tail of the distribution. For this tail and the small distances involved, we shall assume uniformly distributed predators and non-schooled prey.

The distribution of $d_{k'}$ is complicated by r'. A predator sights the school if he comes within the distance of $r + r'$ of the centre of the school. If we think of a single fish as a school of size one, d_{ik} is the distance from the kth predator to the centre of this school. The generalization to thinking of d_{ik} as the distance to the centre of any size school is obvious if we now speak of the ith school rather than the ith fish. Then $d_{k'} = d_{ik} - r'$. Let us denote $E(d_{ik}) \equiv \mu$ and $E(d_{ik}{}^2) - \mu^2 \equiv \sigma^2$ and assume finite means and variances throughout. If r' is taken as constant,

$$E(d_{k'}) = E(d_{ik} - r') = E(d_{ik}) - r' = \mu - r'.\text{ Also}$$

$$E(d_{k'}{}^2) - E^2(d_{k'}) = E(d_{ik}{}^2) - 2r'E(d_{ik}) + r'^2 - (\mu - r')^2 = E(d_{ik}{}^2) - \mu^2 = \sigma^2.$$

If r' is taken to be a variable with mean $\mu_{r'}$ and variance $\sigma^2_{r'}$, $E(d_{ik}r') - \mu\mu_{r'} \equiv \text{cov}(d_{ik}, r') = 0$, and it is simple to show in a similar fashion that $E(d_{k'}) = \mu - \mu_{r'}$ and $E(d_{k'}{}^2) - E^2(d_{k'}) = \sigma^2 + \sigma^2_{r'}$. We shall take r' as constant.

Now since $d_{k'} = d_{ik} - r'$, (17) may be written

$$\frac{n_e}{n_f} < \frac{P[d_{ik} \leq r]}{P[d_{ik} \leq r + r']} \tag{18}$$

In a stable predator and prey relationship, where μ is much larger than either r or r', and under the assumption of uniformity of distribution of fish for the small distances involved in the extreme left tail of the probability distribution, the right side of (18) reduces to the ratio of volumes of water about the ith prey, representing the predator's effective scouting sight range under non-schooled and schooled prey conditions, respectively. Such volumes reduce to three cases: (i) the prey is at a distance greater than $r + r'$ from either the surface of the ocean or some depth below which the fish are unlikely to go, so that the volumes will be spheres. (ii) the prey is at a distance less than $r + r'$ but greater than r from either the surface or this depth so that one volume will be a truncated sphere, i. e., it has lost its cap at one or the other pole. (iii) the prey is at a distance less than r from either the surface and this depth so that both volumes will be spheres truncated on one pole. The last two cases will be discussed for truncation at the top of the sphere, i. e., by the surface of the ocean. If the sphere should be truncated at both poles by both the surface and maximum depth, then the solutions of either or both of cases (ii), (iii) may be used independently to truncate both poles.

Case (i): The volumes are spheres. We have immediately

$$\frac{n_e}{n_f} < \frac{r^3}{(r + r')^3} \tag{19}$$

Case (ii): The smaller volume is a sphere, but the larger volume intersects the surface. Let Φ_1 (>0) denote the angle about the centre of the sphere from horizontal to the intersection of the sphere with the surface. Then (18) becomes

$$\frac{n_e}{n_f} < \frac{\frac{4}{3}\pi r^3}{\frac{2}{3}\pi(r + r')^3 + \frac{2}{3}\pi(r + r')^3(1 - \cos\Phi_1) + \frac{1}{3}\pi[(r + r')^3\sin\Phi_1 - (r + r')^3\sin^3\Phi_1]} \tag{20}$$

where the first term of the denominator is the lower half of the volume of the total sphere, the second term is the area of the sector of the great circle between 0 and Φ_1 rotated 2π $\left(\text{explicitly} \int_0^{2\pi}\int_0^{\Phi_1}\int_0^{r+r'} r^2 \sin\Phi_1 \, dr \, d\Phi_1 \, d\theta\right)$, and the third term is the usual formula for the volume of a cone, which of course is the remaining volume of the figure where $(r + r')\sin\Phi_1$ is the distance from the centre of the sphere to the surface.

(20) reduces easily to

$$\frac{n_e}{n_f} < \frac{r^3}{(r + r')^3\,[1 - \frac{1}{2}\cos\Phi_1\,(1 - \frac{1}{2}\sin\Phi_1)]} \tag{21}$$

If $\Phi_1 = \pi/2$, (21) reduces to (19), which is obvious since the sphere will not be truncated. For any $\Phi_1 < \pi/2$, the quantity in brackets in (21) is always positive and less than unity, so that the right side of (21) is always greater than the right side of (19), implying an advantage to prey if the centre of the school is less than $r + r'$ but greater than r from the surface (or alternatively if the predator is in the equivalent position, which reduces his effective scouting volume).

Case (iii): Both the smaller volume and the larger volume intersect the surface. Let Φ_1 (>0) denote the angle about the centre of the sphere from horizontal to the intersection of the larger sphere with the surface; let Φ_2 (>0) denote the similar angle for the smaller sphere. Then (18) becomes

$$\frac{n_e}{n_f} < \frac{\frac{2}{3}\pi r^3 + \frac{2}{3}\pi r^3(1 - \cos\Phi_2) + \frac{1}{3}\pi\,[r^3\sin\Phi_2 - r^3\sin^3\Phi_2]}{\frac{2}{3}\pi(r + r')^3 + \frac{2}{3}\pi(r + r')^3(1 - \cos\Phi_1) + \frac{1}{3}\pi\,[(r + r')^3\sin\Phi_1 - (r + r')^3\sin^3\Phi_1]} \tag{22}$$

in which both numerator and denominator of the right side are obtained as the analogous expression in (20). (22) reduces easily to

$$\frac{n_e}{n_f} < \frac{r^3\,[1 - \frac{1}{2}\cos\Phi_2\,(1 - \frac{1}{2}\sin\Phi_2)]}{(r + r')^3\,[1 - \frac{1}{2}\cos\Phi_1\,(1 - \frac{1}{2}\sin\Phi_1)]} \tag{23}$$

If $\Phi_1 = \Phi_2 = 0$, (23) reduces to (19), which is obvious since the same proportion is truncated from each sphere. Note that for $\Phi_1 > 0$,
$1 - \frac{1}{2} \cos \Phi_2 \, (1 - \frac{1}{2} \sin \Phi_2) > 1 - \frac{1}{2} \cos \Phi_1 \, (1 - \frac{1}{2} \sin \Phi_1)$
which may be written

$$\frac{\cos \Phi_2}{\cos \Phi_1} < \frac{1 - \frac{1}{2} \sin \Phi_1}{1 - \frac{1}{2} \sin \Phi_2} \tag{24}$$

which is always true since $\Phi_2 > \Phi_1$. Thus, the right side of (23) is greater than the right side of (19), implying an advantage to prey if the centre of the school is less than r from (but not actually on) the surface (or alternatively if the predator is in the equivalent position).

Since (21) and (23) imply an advantage to prey if a predator is too close to the surface or some limiting depth, which may be the bottom, we shall discuss the most conservative result, viz. (19). If (19) be written

$$n_e < \frac{r^3}{(r + r')^3} \, n_f, \tag{25}$$

we see that the number of schooled prey a predator must consume after locating a school of prey in order to nullify the advantage the prey gain by schooling is the fraction $r^3/(r + r')^3$ of the total prey in the school.

If we think of a school of n_f prey as being spherical in shape and having all fish distributed uniformly therein, r' is the radius of this sphere and the prey will be some constant number of distance units, say c, apart along a radius. Then there are $\frac{r'}{c}$ prey along a radius, from which we immediately obtain

$$n_f = \frac{4\pi}{3} \left(\frac{r'}{c} \right)^3 \tag{26}$$

or

$$r' = c \sqrt[3]{\frac{3 n_f}{4\pi}}. \tag{27}$$

Thus r' is a function of c, n_f and upon substituting (27) into (25) we obtain

$$n_e < \frac{r^3 \, n_f}{\left(r + c \sqrt[3]{\frac{3 n_f}{4\pi}} \right)^3} \tag{28}$$

For fixed n_f, as c approaches zero, the right side of (28) approaches n_f, which implies that as the prey in a school draw closer together, a predator must be able to consume more and more nearly the entire school in order to nullify schooling advantage. Here the detection advantage increases as the prey draw close together while the frequency of encounter advantage and predator capacity advantage remain unchanged.

Now let us see what happens when c grows larger. The largest c can grow is r; we are assuming only visual communication in our model so that when $c > r$ the prey cannot see one another and thus cannot communicate so that the school ceases to exist by definition. Then since the most disadvantageous c admissible is $c = r$, let us investigate (28) for $c = r$. r cancels in (28) when $c = r$, leaving

$$n_e < \frac{n_f}{\left(1 + 0{\cdot}6204 \sqrt[3]{n_f}\right)^3} \tag{29}$$

This inequality is violated for most reasonable sizes of n_f. For example, if the predator can eat only four prey, which is rather a small number, the schooling advantage is not gained until the school reaches 1,000,000 in size. It is obvious that fish do not school with distances apart approaching the sight range when visual distances are good, but this result shows that schooling in extremely turbid waters or at night may work to the disadvantage of the prey. There exists considerable observation to indicate that schools tend to break up at night and that there is little schooling in waters having poor visual properties. The exact sight range r at which schooling gives neither advantage nor disadvantage will depend upon n_f, n_e, and c, and can be obtained from (28) for any desired values of these variables.

Some values of n_e from (28) for selected values of n_f, r, and c are shown in Table 1.

Table 1

Values of n_e (rounded to the whole fish), larger than which will violate (28), for various n_f and r with c fixed at 4 feet

(Thus in a school of 1,000 prey distributed 4 feet apart, a predator must consume 514 prey to nullify schooling advantage if the sight range is 100 feet, but only 3 prey if the sight range is 4 feet, i. e., the distance apart.)

n_f	$r = 200$ ft.	$r = 100$ ft.	$r = 10$ ft.	$r = 4$ ft. ($= c$)
1	1	1	1	0
10	9	9	3	1
100	85	72	10	2
1,000	704	514	24	3
10,000	4,913	2,767	39	3
1,000,000	88,877	23,695	57	4

If r and c are assumed to be constant and n_f be given various values, the ratio between schooled and scattered prey, viz. (28) will under conditions of uniform abundance of predators and prey, give the frequency of encounter of schooled prey by the predators. Once a school is sufficiently large so as not to be totally consumed during the period of encounter by a predator, further increases in school size would not increase the quantity of prey consumed under these assumptions.

As n_f is increased, the frequency of encounter is reduced, and assuming n_e constant for each encounter, the average amount of prey consumed per unit time is likewise reduced. Obviously there exists some minimal rate of consumption that will permit the survival of the predator, and some maximal rate that depends upon the digestive capacity of the predator.

Let us further illustrate the use of the inequality (28) with some reasonable values drawn in part from observation. From observations and photographs taken from an underwater observation port on the research vessel of the Honolulu Biological Laboratory, schooled skipjack are about 2 feet apart or about 4 feet between the centres of any two fish. The sight range, r, is conservatively, 100 feet. If a marlin, preying on skipjack, eats during an average encounter with a school, some 40 pounds, and skipjack are abundant enough to supply this amount of prey daily if not schooled, the daily consumption rate will vary with school size as shown in Table 2.

Table 2

Variation of consumption rate by a predator with prey school size based on model in text

School size	Daily weight of fish eaten in pounds
1	40
10	4·68
100	0·55
1000	0·08

A school of 2,000 skipjack of 10 pounds average weight would occupy a sphere of about 31·3 feet in radius, and from (28) the marlin must eat $\frac{(100)^3}{(131\cdot3)^3} = \frac{1{,}000{,}000}{2{,}262{,}020} = 0\cdot442$ of the school or 8,840 pounds during the period of encounter to nullify the schooling advantage.

To illustrate again, let us note that the average successful purse seine set about a pilchard school in British Columbia produced 35 tons while sets upwards of 100 tons were not unknown (HART, 1933). Schools of other marine pelagic fishes reach similar if not greater magnitude. For a large part of such schools to be consumed by a predator, even assuming that he remains with the school for a long period and that the school permits his presence without disintegrating, is quite impossible. If the prey should adopt the strategy (and there is some evidence that this occurs) of disintegrating the large school when sighted by a predator and later reforming, the predator could not physically remain with more than one segment of the school, which puts physical as well as physiological limits on n_e, and thus schooling could not be other than advantageous to the prey under optimum strategy.

Thus far we have discussed $P[d_{ik} \leq r]$ and $P[d_{k'} \leq r]$ only in ratio; this is satisfactory if we are strictly comparing advantages of schooling to non-schooling. However, if we should be interested in estimating one or both of these probabilities in order to describe what actually occurs in the pelagic ecology rather than to assess strategies, then we should have to deal with one of the probabilities alone. It is of interest to note that $P[d_{ik} \leq r]$ and $P[d_{k'} \leq r]$ are very nearly zero and approximately equal, since they both represent small areas under the extreme tail of a probability curve. Since we do not know the probability functions exactly, we cannot evaluate exactly these probabilities, but let us demonstrate what happens approximately by taking the bell-shaped curves discussed earlier to be approximately normal. Under this assumption, d_{ik} is a random variable distributed as a truncated $n(\mu, \sigma^2)$, since $0 \leq d_{ik} < \infty$. Using the notation of CRAMÉR (1946) in which

$$\varphi(y) = \int_{-\infty}^{y} n(0,1)\, dt,$$

we have

$$(30)\qquad P[d_{ik} \leq r] = \frac{\varphi\left(\frac{r-\mu}{\sigma}\right) - \varphi\left(-\frac{\mu}{\sigma}\right)}{1-\varphi\left(-\frac{\mu}{\sigma}\right)}$$

and

$$(31)\qquad P[d_{k'} \leq r] = P[d_{ik} \leq r + r'] = \frac{\varphi\left(\frac{r+r'-\mu}{\sigma}\right) - \varphi\left(\frac{r'-\mu}{\sigma}\right)}{1-\varphi\left(\frac{r'-\mu}{\sigma}\right)}$$

which are approximately equal.

To illustrate, let us find parameter values from a situation which may be taken as reasonable. The maxima of r and r' may reasonably be restricted to the order of magnitude of a few hundred feet or less, say 0·03 nautical miles. In the Marquesas Islands, it has been found that schools of skipjack are sighted about every four nautical miles along a transect of ocean surface. It is reasonable that schools average about 10 tons, and that marlin are in weight about 1/50 as abundant. If a marlin weights 200 pounds, then there will be about two marlin per school along the transect, yielding $\mu \doteq 2$ miles. Let us note the similarity between the left-truncated normal and the poisson distribution and use the poisson property that $\mu = \sigma^2$, so that $\sigma \doteq \sqrt{2}$ or about 1·4. Let us take 100 feet $\doteq$ 0·012 as reasonable values of both r and r'. Substituting these values in the probability values of both sides of (21), we obtain respectively

$$\frac{\varphi\,(1{\cdot}42) - \varphi\,(1{\cdot}41)}{\varphi\,(1{\cdot}42)},\quad \frac{\varphi\,(1{\cdot}43) - \varphi\,(1{\cdot}42)}{\varphi\,(1{\cdot}43)}$$

or, upon evaluating,

·0015940, ·0015590,

which are approximately the same.

Discussion

The assumptions made and conclusions reached herein are admittedly not related to the observed behaviour pattern of any particular species of fish, however, the relationships of school size of prey and encounter frequencies between prey and predators may, for a particular prey-predator combination, be a more complex situation elaborated from that described here. For example, predators may attempt to remain with a school of prey even though satiated, and it is not unlikely that a large school of prey may leave an easily detectable trail of odour behind for a predator to follow. While fish schools of some species do remain together during darkness as indicated for the California sardine by a night fishery (LINDNER, 1930) yet even here the dispersion of tagged fish through the stock as indicated by recovery patterns would argue that a substantial interchange of individuals among schools must occur at least which suggests the possibility of the dispersal and reforming of schools.

The general lack of field data concerning the behaviour pattern for a prey species and its predators renders either the confirmation or refutation of the conclusions reached in this paper by the elaboration of some scheme of predator strategy rather futile. Hiatt and Brock (1948) described the herding of a small school of mackerel scad (*Decapterus*) by a few little tuna (*Euthynnus*) which would seem to constitute a more elaborate strategy than implied here. We do not conclude that complex strategies do not exist; we do suggest, however, that the relationships among predators, prey, and prey school sizes, described here, may be basic to such strategies.

Summary

The schooling of fish is considered as a mechanism for protection against predation. It is shown that the frequency of detection of prey by a predator is an inverse function of the number of schooled or grouped prey. The quantity of fish that a predator can consume on any single encounter with a school of prey has some average limit, and once school size exceeds this quantity, further increases in school size reduce the frequency of predator-prey encounters without necessarily changing the quantity of prey consumed on the occasion of each encounter, which in turn may reduce the rate of consumption of a prey species by a predator.

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Two New Species of *Candacia* (Copepoda: Calanoida) from the Central Pacific, with Notes on Two Other Species[1]

GEORGE D. GRICE[2] and EVERET C. JONES[3]

DURING EXAMINATION of plankton samples collected from the central Pacific Ocean by the Honolulu Biological Laboratory (formerly Pacific Oceanic Fishery Investigations) of the U. S. Fish and Wildlife Service, two species of *Candacia* were found which appear to be undescribed. In addition to describing these two species we present evidence that *Candacia turgida* Wilson is a synonym of *C. truncata* (Dana). We also include a description and figures of *Candacia norvegica* (Boeck), a species apparently rare in the Pacific Ocean.

We wish to acknowledge the help of Dr. Thomas E. Bowman in loaning us type material from the U. S. National Museum, and that of Dr. Paul L. Illg for valuable suggestions during the preparation of the type material and the manuscript.

Candacia pofi new species
Figs. 1–21

LOCALITY AND MATERIALS: 1° 23′ S., 112° 46′ W. (U. S. Fish and Wildlife Service "Hugh M. Smith" cruise 31, station 75-3, Oct. 31, 1955, 200–140 m. depth of tow; 23 females and 6 males). Physical, oceanographic, and other data from this cruise have been published by King, Austin, and Doty (1957).

Type material of *Candacia pofi* has been deposited in the U. S. National Museum as follows: Female holotype (USNM 102730), male allotype (USNM 102731), 22 female paratypes and 5 male paratypes (USNM 102732).

MEASUREMENTS: Measurements were made from a dorsal view along a sagittal plane. The abdomen was supported by a plastic strip to reduce flexion. The copepod, stained with methyl blue and immersed in lactic acid, was mounted under a cover slip supported by plastic strips to avoid distortion due to pressure or a meniscus. The total length was measured from the anterior margin of the head to the ends of the caudal furca. The abdomen was measured from the anterior margin of the genital segment to the ends of the caudal furca. These measurements excluded the telescoped portions of the abdominal segments. The ratios of the lengths of the abdominal segments, however, include the telescoped portions as indicated by dotted lines in the figures. Pertinent measurements and ratios of the cephalothorax and abdomen of the holotype, allotype, 3 female paratypes, and 4 male paratypes are given in Table 1.

DESCRIPTION: In the adult female the cephalothorax (Fig. 1) is slender, being widest at the first thoracic segment. The posterior lateral angles of the thorax are produced into sharp symmetrical processes which reach to a line including 60 per cent of the length of the genital segment (Fig. 3). The genital segment (Fig. 3) is symmetrical in dorsal view, longer than wide and without lateral swellings or processes. The genital pore is situated on a very large protuberance which extends ventrad and caudad. In lateral view (Figs. 2, 4), the posterior margin of this protuberance is approximately continuous with the posterior margin of the genital segment. In ventral view (Fig. 5), the genital protuberance is round with a slight lip at the posterior margin. In the holotype, this lip is slightly asymmetrical. The second abdominal segment (Fig. 3) is asymmetrical in dorsal view, the right margin being convex and the left margin straight. The ventral surface is wrinkled and bears a low process which extends to the left as a lobe with a more or less crenulate margin.

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[1] Contribution No. 131, Hawaii Marine Laboratory, University of Hawaii, with which one of the authors (G. D. G.) was associated. Manuscript received January 16, 1959.

[2] Fellow of the John Simon Guggenheim Memorial Foundation, 1958–59. Present address: Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

[3] Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii.

The dorsal surface of the anal segment (Fig. 3) bears a very prominent, broad bifurcate process pointing caudad. The posterior lateral surface of each of the diverging tubercles of this process has a patch of very fine teeth visible under 100× magnification. In the holotype, these tubercles appear to be slightly asymmetrical in size and in details of minute swellings and creases. Examination of paratype material indicates that there is variation in these details and also in the ventral lobe of the second abdominal segment.

The furcal rami (Fig. 3) are longer than wide. The outermost furcal setae are thick and originate high on the lateral margins of the rami. There is a small tooth dorsad of the origin of the middle major seta of each ramus.

The proximal seven segments of the first antennae are thickened. The first segment has three small spines, and segments 2 through 6 have small marginal spines (Fig. 6). It is probable that additional segments had spines which have been lost in the material at hand.

The second antennae are similar to those of other members of the genus. The exopod has six setae plus a minute one; the second endopodal segment is divided into two lobes, the external with six setae plus a minute one and the internal with five setae plus a minute one.

The exopod of the mandibular palpus has five setae; the endopod has six. The mandibular blades (Fig. 7) are composed of a large point and a basal tooth with three points decreasing in length mediad.

The first maxillae are best described by reference to Figure 8.

The second maxillae (Fig. 9) are large and have the form of maxillipeds. The basal segment is composed of four lobes. There is a single long seta on the first lobe with a minute seta at its base, two small setae on the internal margin of the second lobe, and one large spine with a short spine at its base on each of the third and fourth lobes. There are two long spines of about equal length on the second basipodal segment, and the proximal one has a minute spine at its base. Distad of the second basipodal segment are three very long, curved spines, the middle of which is the longest. Three very small bristles arise from the base of the distal spine.

The maxillipeds are reduced in length (Fig. 10). The first segment is about as long as the remaining segments combined and is 1.7 times the length of the second. There is a tubercle on the internal margin of the first segment near the proximal end and a single long seta just distad of the midpoint of that margin. Two slender setae, one twice the length of the other, arise from the junction of the first and second segments. At about the midpoint of the internal margin of the second segment, there is a patch of hair proximad of three setae. The distal end of this segment appears to receive the proximal end of the third so that the second and third each have three setae. Vervoort (1957), in describing *C. maxima,* attributes four setae to the second segment and two to the third. Giesbrecht (1892, pl. 21, figs. 26, 27) indicates that in *C. longimana* Claus the fourth seta is between the two segments but in *C. bispinosa* Claus it is on the third segment. This appendage is usually regarded as having little diagnostic value, but the origin of the fourth seta might add a distinguishing character. The fourth, fifth, and sixth segments have a pair of setae, the distal one in each pair being longer. Distad of the sixth segment are two long setae of almost equal length.

The lengths of the third exopodal segments of swimming feet 1 to 4 (Figs. 11–14) have the following relation to that of their respective terminal spines: 1:1, 2:1, 3:1, and 3:2.

The symmetrical fifth feet (Fig. 15) are long and slender, each ending in two sharp, smooth terminal fingers. The inner finger is about four times the length of the outer finger. There are two external spinous processes located at points about one-fourth and two-thirds of the segment length from the proximal end of the distal segment. There are no internal spines or setae. The penultimate segment bears a single seta, and the ratio of the length of that segment to that of the distal segment is 1:4.6.

Brown pigmentation in the female is restricted to the following structures: the fifteenth segment of the first antennae, the setae of the second antennae and the mandibular palpi, the second segment of the second max-

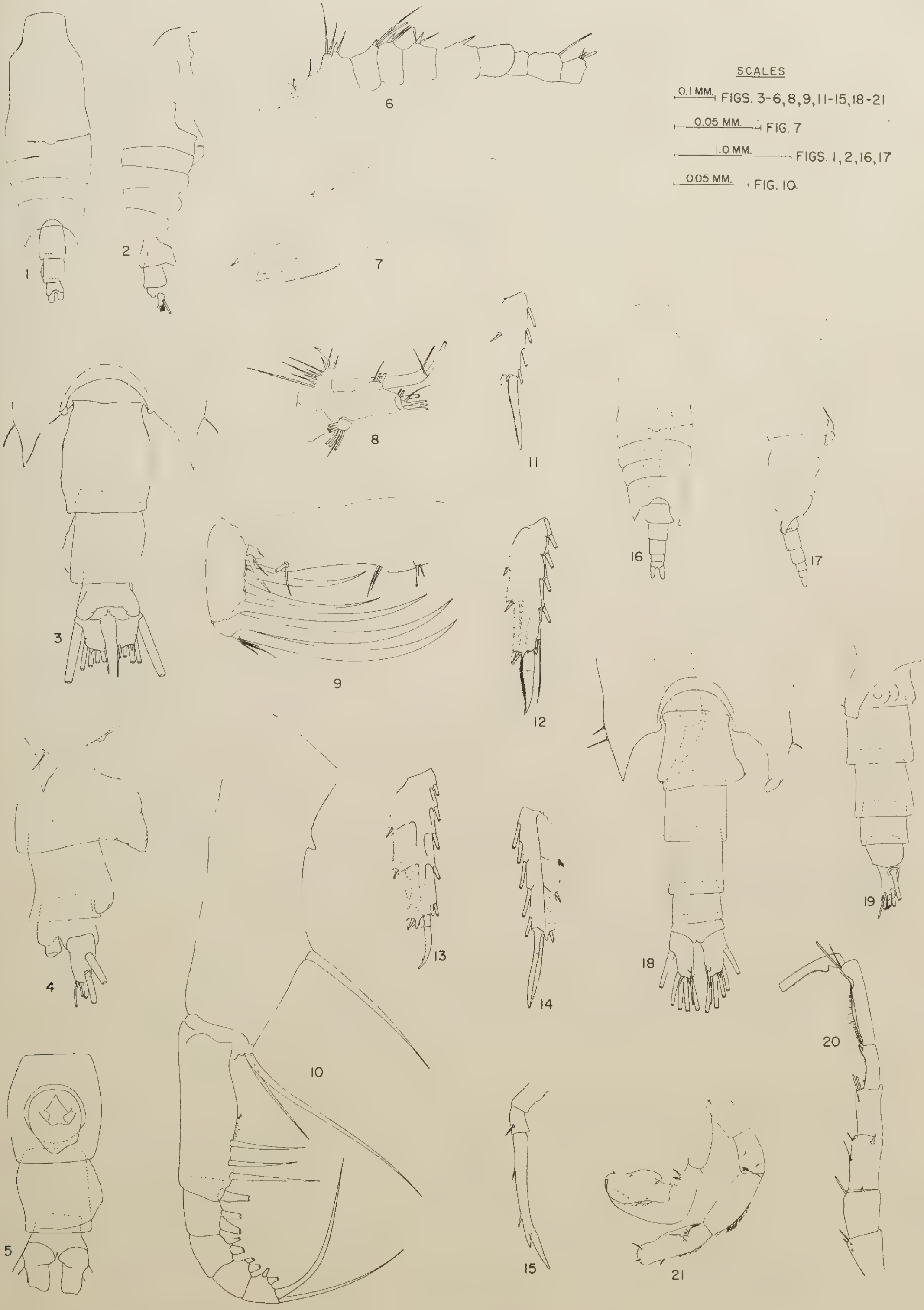

SCALES
0.1 MM. FIGS. 3-6, 8, 9, 11-15, 18-21
0.05 MM. FIG. 7
1.0 MM. FIGS. 1, 2, 16, 17
0.05 MM. FIG. 10

TABLE 1
TOTAL LENGTHS, CEPHALOTHORAX–ABDOMEN RATIOS, AND ABDOMINAL SEGMENT RATIOS OF *Candacia pofi*

SPECIMENS	TOTAL LENGTH (mm.)	CEPHALOTHORAX–ABDOMEN RATIO	RELATIVE LENGTH OF ABDOMINAL SEGMENTS						
			1	2	3	4	5	Furca	
Females									
Holotype	2.30	2.75:1	38	32	16	...	...	14	= 100
Paratype	2.41	2.64:1	42	30	16	...	...	12	= 100
Paratype	2.41	2.55:1	41	32	16	...	...	11	= 100
Paratype	2.36	2.75:1	39	29	17	...	...	15	= 100
Males									
Allotype	2.28	2.52:1	21	21	21	14	9	14	= 100
Paratype	2.21	2.61:1	21	21	21	14	9	14	= 100
Paratype	2.24	2.38:1	21	21	21	14	9	14	= 100
Paratype	2.23	2.54:1	...	...	...	...	...	...	...
Paratype	2.21	2.43:1	...	...	...	...	...	...	...

illae, the third exopodal segments of swimming feet 1 to 4, and the furcal setae.

The pertinent measurements and ratios of the adult males are presented in Table 1. The posterior lateral angles of the male cephalothorax (Fig. 16) are produced into asymmetrical processes. The left is sharp and reaches to the posterior margin of the genital segment. The right process (Fig. 18) is thick and slightly curved inward and reaches to a line including one-quarter of the length of the second abdominal segment. In lateral view (Figs. 17, 19), this right process is thick and truncate with a convex dorsal margin and a concave ventral margin.

The male genital segment (Fig. 18) is asymmetrical with a rounded swelling tipped with a small button on the right side. In lateral view (Fig. 19) the swelling appears as two or three concentric, incomplete circles. The left posterior margin of the genital segment is broken by the genital opening. In the allotype, a canal is visible from the genital opening to a spermatophore (Fig. 18).

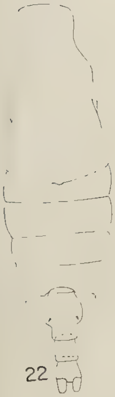
The geniculate right antenna (Fig. 20) is armed with coarse, unequal pigmented teeth on segment 18, fine pectination on segment 17 extending onto the anterior margin of a distal spinous process, and very fine pectination on segment 19. Segments 17, 18, 19, and 20 are separate.

The right fifth foot (Fig. 21) is chelate with the tip of the distal segment reaching slightly beyond that of the penultimate segment. The terminal spine is turned flat against the surface of the distal segment. The left fifth foot is broad and ends in a spatulate segment (Fig. 21).

Pigmentation is similar to that of the female. In addition, the geniculate portions of the right first antenna are heavily pigmented. There is no pigmentation on the right thoracic process or the genital segment.

REMARKS: The female of *C. pofi* resembles *C. cheirura* Cleve (as described by Farran, 1929) in having ventral protuberances on the genital and second abdominal segments, and thick ex-

FIGS. 1–21. *Candacia pofi* n. sp. 1, female, dorsal view; 2, female, lateral view; 3, fourth and fifth thoracic segments and abdomen, dorsal view, female; 4, fourth and fifth thoracic segments and abdomen, lateral view, female; 5, abdomen, ventral view, female; 6, proximal 10 segments of first antenna, female; 7, mandibular blade, female; 8, first maxilla, female; 9, second maxilla, female; 10, maxilliped, female; 11, third exopodal segment of first foot, female; 12, third exopodal segment of second foot, female; 13, third exopodal segment of third foot, female; 14, third exopodal segment of fourth foot, female; 15, fifth foot, female; 16, male, dorsal view; 17, male, lateral view; 18, fourth and fifth thoracic segments and abdomen, dorsal view, male; 19, fourth and fifth thoracic segments and abdomen, lateral view, male; 20, segments 13 through 19, right first antenna, male; 21, fifth feet, male. Figures 1–12 and 15 drawn from holotype; Figures 13 and 14 from paratype. Figures 16–19 and 21 drawn from allotype; Figure 20 from paratype.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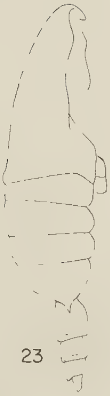
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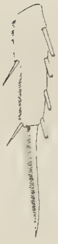
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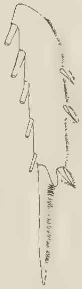
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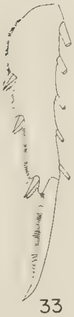
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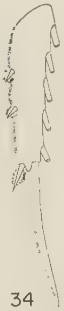
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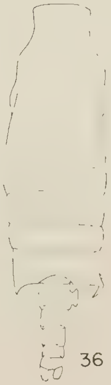
SCALES

0.5 MM. FIGS. 22, 23, 36, 37

0.05 MM. FIGS. 27, 30, 35

0.1 MM. FIGS. 28, 31-34, 40, 41

0.1 MM. FIGS. 24-26, 29, 38, 39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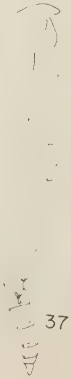
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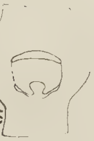
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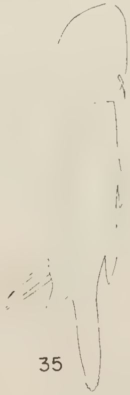
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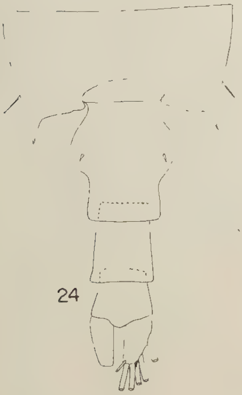
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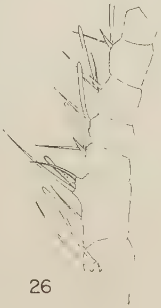
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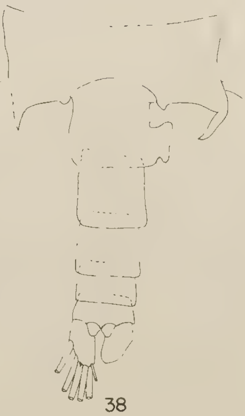
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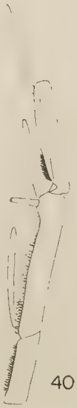
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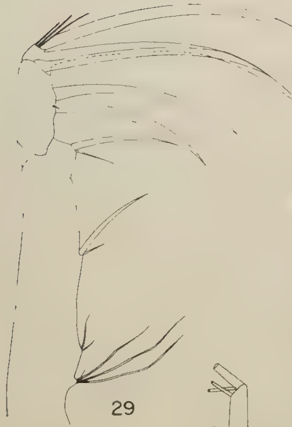
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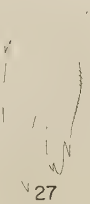
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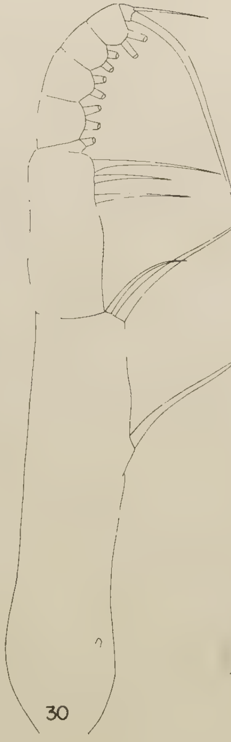
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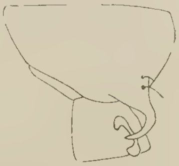
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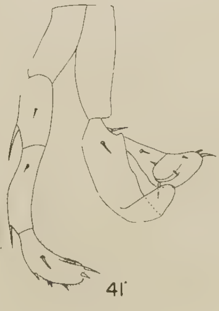
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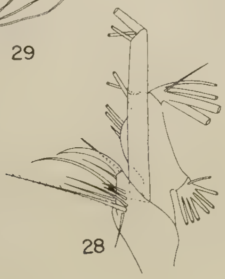
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ternal furcal setae. It can be distinguished from *C. cheirura* by the asymmetry of the abdomen in dorsal view and by the presence of dorsal tubercles on the anal segment. The female resembles *C. armata* Boeck (as described by G. O. Sars, 1903) in having an asymmetrical second abdominal segment. It can be distinguished from this species by the extremely large genital protuberance, the ventral lobe of the second abdominal segment extending to the left rather than to the right, the dorsal tubercles on the anal segment, and details of the fifth feet.

The geniculate antenna of the male *C. pofi* resembles that of *C. armata* Boeck (as described by Sars, 1903), *C. bradyi* and *C. discaudata* A. Scott, *C. bipinnata* Giesbrecht, and *C. cheirura* Cleve in having segments 17, 18, 19, and 20 separate and in having coarse, unequal pigmented teeth on segment 18. *C. pofi* can be distinguished from *C. bradyi* and *C. discaudata* by the produced right thoracic process. It can be distinguished from *C. armata, C. bipinnata,* and *C. cheirura* by the low, rounded genital process in lieu of the sharp spinous process in those species. The name of this species is derived from Pacific Oceanic Fishery Investigations.

Candacia guggenheimi new species
Figs. 22–41

LOCALITIES AND MATERIALS: 26° 25.2′ N., 155° 03.0′ W. (U. S. Fish and Wildlife Service "Hugh M. Smith" cruise 25, sta. 33, Feb. 10, 1954, 200–0 m. depth of tow, 2 females, 4 males); 32° 33′ N., 148° 51.5′ W. ("Hugh M. Smith" cruise 25, sta. 53, Feb. 22, 1954, 200–0 m. depth of tow, 1 male); 23° 56′ N., 157° 31′ W. ("Hugh M. Smith" cruise 30, sta. 112-1, Aug. 27, 1955, 140–0 m. depth of tow, 1 female); 21° 55′ N., 158° 08′ W. ("Hugh M. Smith" cruise 32, sta. 26, Feb. 5, 1956, 200–140 m. depth of tow, 1 female, 1 male); 0° 00′, 149° 38′ W. ("Hugh M. Smith" cruise 47, sta. 29, Oct. 27, 1958, 500 m. depth of tow, 1 female). This species has also been observed in samples collected at the following stations on "Hugh M. Smith" cruise 25 (all 200–0 m. collections): 21° 36.5′ N., 159° 00′ W. (sta. 2, Jan. 16, 1954); 33° 55.7′ N., 164° 58.5′ W. (sta. 11, Jan. 22, 1954); 26° 31′ N., 160° 00′ W. (sta. 26, Jan. 30, 1954); 22° 03.7′ N., 158° 40′ W. (sta. 29, Feb. 1, 1954); 29° 32′ N., 155° 04.8′ W. (sta. 35, Feb. 12, 1954); 32° 30′ N., 154° 59′ W. (sta. 37, Feb. 13, 1954). Physical, oceanographic, and other data for cruise 25 have been summarized by McGary and Stroup (1956) and that for cruise 30 by McGary, Jones, and Austin (1956).

Type material of *C. guggenheimi* has been deposited in the U. S. National Museum. A female from cruise 25, sta. 33, was selected as the holotype (USNM 102733). A male from this station was designated the allotype (USNM 102734). Paratypes are as follows: 1 female, 3 males, cruise 25, sta. 33 (USNM 102735); 1 male, cruise 25, sta. 53 (USNM 102736); 1 female, cruise 30, sta. 112-1 (USNM 102737); 1 female, 1 male, cruise 32, sta. 26 (USNM 102738); 1 female, cruise 47, sta. 29 (USNM 102739).

MEASUREMENTS: All measurements were made in the method described for the preceding species. The total length of five adult females ranges from 1.94 to 2.06 mm. The lengths and cephalothorax–abdomen ratios, based on three of these individuals are: holotype 2.01 mm., 2.9:1; paratypes 1.96 mm., 2.8:1; 2.04 mm., 3.1:1.

The total length of six adult males varies from 1.90 to 2.00 mm. These lengths and the

FIGS. 22–41. *Candacia guggenheimi* n. sp. 22, female, dorsal view; 23, female, lateral view; 24, fourth and fifth thoracic segments and abdomen, dorsal view, female; 25, genital segment, ventral view, female; 26, proximal seven segments of first antenna, female; 27, mandibular blade, female; 28, first maxilla, female; 29, second maxilla, female; 30, maxilliped, female; 31, third exopodal segment of first foot, female; 32, third exopodal segment of second foot, female; 33, third exopodal segment of third foot, female; 34, third exopodal segment of fourth foot, female; 35, fifth foot, female; 36, male, dorsal view; 37, male, lateral view; 38, fourth and fifth thoracic segments and abdomen, dorsal view, male; 39, fourth and fifth thoracic segments and genital segment, lateral view, male; 40, segments 17 through 19, right first antenna, male; 41, fifth feet, male. Figures 22, 23, 27, and 34 drawn from paratype; Figures 24–26, 28–33, and 35 drawn from holotype. Figures 36–39 and 41 drawn from allotype; Figure 40 drawn from paratype.

cephalothorax–abdomen ratios, based on four of these, are: allotype 1.90 mm., 2.91:1; paratypes 1.92 mm., 2.9:1; 1.94 mm., 2.7:1; 2.00 mm., 2.7:1.

DESCRIPTION: The general shape of the adult female is similar to other species of the genus *Candacia.* The head is truncate in dorsal view; thoracic segments 4 and 5 are fused and produced posteriorly into two symmetrical points (Fig. 22). In lateral view (Fig. 23), a small hump is visible on the dorsal surface at the junction of the head and first thoracic segment.

The genital segment is slightly asymmetrical; the lateral swelling on the left side is smaller and somewhat more expanded than that on the right side (Figs. 24, 25). A single dorsal spine is present on each swelling. The abdominal segments and furca have the following proportions (based on holotype): 40, 26, 19, 15 = 100.

The first antennae, when held against the body, reach to about the tips of the furcal rami. The proximal part of the antenna is thickened and consists of seven segments (Fig. 26). Segments 1 through 6 and 8 through 12 have one spine. There are indications that additional segments are furnished with a spine but no perfect antennae were present among the specimens examined.

The second antennae are similar to those of other species of *Candacia.* Basipodal segments 1 and 2 have one seta. Segment 2 of the endopod ends in two lobes. The outer lobe has six large and one small setae. The inner lobe has five large and one small setae and one minute seta proximad of the small one.

The exopod of the mandible apparently consists of four segments, the first three of which are furnished with a single seta. The terminal segment has two setae. The endopod is composed of one segment which is provided with six setae. The basal tooth of the mandible is furnished with two subequal points and a marginal point (Fig. 27).

The first maxillae are best described by reference to Figure 28.

The second maxillae are of large size (Fig. 29). The basal segment has four lobes. There are three long and one very short setae on the first lobe, one long and one short seta on the second lobe, one long and one short spine on the third lobe, and one long and one short spine on the fourth lobe. The second basipod segment has two subequal spines, the proximal one has a minute spine at its base. The endopod is furnished with three spines, the middle of which is slightly longest. In addition there are three bristles on the terminal part of the endopod.

The maxillipeds (Fig. 30) are small. The first basal segment is more than twice as long as the second basal segment. The former has one seta at a point about two-thirds of the segment length from the proximal end and two setae on the distolateral corner. The second basal segment is furnished with three unequal setae and one other seta on the apparent apex. Hair is present on the internal margin of this segment. The five endopodal segments are each furnished with one long and one short seta. The long seta on the terminal segment is somewhat longer than those on the other endopodal segments.

The third exopodal segments of swimming feet 1 to 4 are shown in Figures 31–34. The relative lengths of these segments to their respective terminal spines are as follows (based on several specimens): 1:1, 1:0.8 (estimate), 1:0.6, and 1:1.

The fifth feet are symmetrical and each terminates in one long stout finger and one short spinous process (Fig. 35). The former is about three times longer than the latter. The finger has several rounded serrations distally, and the spinous process is finely serrate. The external margin of the segment has two spinous processes. The internal margin bears two subequal setae in all observed specimens except one ("Hugh M. Smith" cruise 47, sta. 29-1) which has three internal setae on one foot.

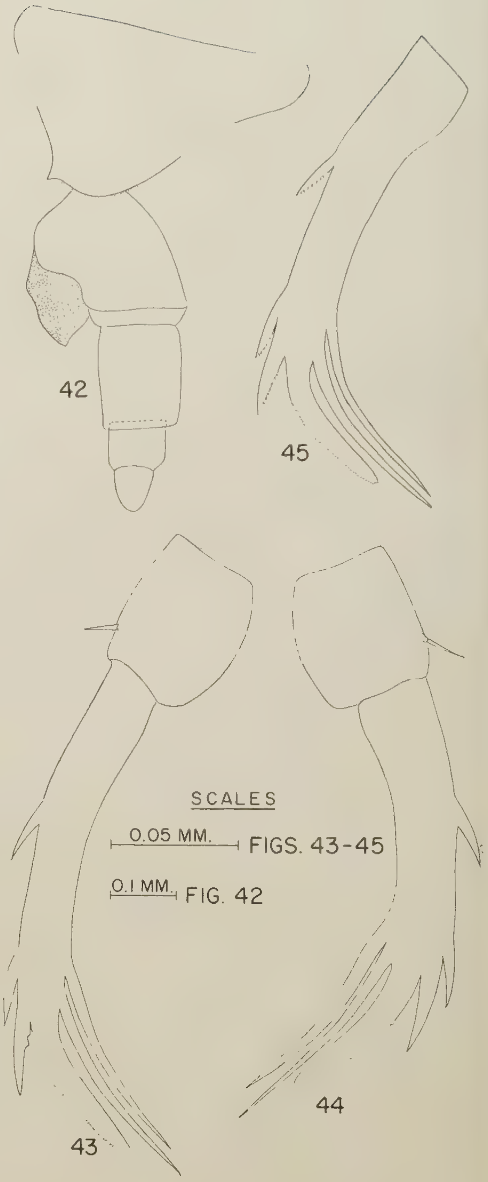
The following appendages of the preserved holotype are pigmented: the distal 18 segments of the first antennae, the distal spinelike claw on the first inner lobe of the first maxillae, portions of the first basipod segment and the distal five spines of the second maxillae, basipodal segments 1 and 2 of the first four pairs of swimming feet, and the terminal finger and spinous process of the fifth pair of feet. The female collected on "Hugh M. Smith" cruise 47, sta. 29, has additional pigmentation as follows: the distal 20 segments of first antennae, the spines on lobes 3 and 4 of the second maxillae, much of both rami of swimming feet 1 to 4 including several setae on the second and third exopodal segments and second endopodal segment, and the first basipodal segment of the fifth pair of feet.

The adult male (Figs. 36, 37) is slightly smaller than the female. The right posterior lateral process of the fifth thoracic segment is produced posteriorly and curved inward in dorsal view (Fig. 38). It reaches to the middle of the protrusion on the genital segment. In lateral view, the thoracic process has a decided upward bend (Fig. 39). The genital segment has a bilobed protrusion arising from near the posterior end of the right margin (Fig. 38). The abdominal segments and furca have the following ratios (based on three specimens): 22, 24, 20, 13, 9, 12 = 100.

Segments 17, 18, 19, and 20 of the right first antenna (Fig. 40) are separate, with 17, 18, and 19 toothed. The nearly uniform teeth on segment 18 are coarser than those on segments 17 and 19. The fifth feet are shown in Figure 41.

The following body parts and appendages of the male are pigmented (based on examination of several specimens): segments 17 to 25 of the right antenna, the distal 17 segments of the left antenna, the process on the right corner of the fifth thoracic segment, the clawlike spine on the distal part of the first inner lobe of the first maxillae, portions of the first basipod and spines on lobes 3 and 4 and the five large distal spines of the second maxillae, basipodal segments 1 and 2 of swimming feet 1 to 4.

REMARKS: The female of *C. guggenheimi* superficially resembles *C. longimana* Claus. The spines on the dorsal surface of the genital segment, the structure of the fifth pair of feet, and the somewhat smaller size of this species readily distinguish it from *C. longimana.* The bilobed protrusion on the genital segment and the structure of the fifth feet serve to distinguish the male. This species is named for the late Simon Guggenheim, one of the founders of the John Simon Guggenheim Memorial Foundation.



FIGS. 42–45. *Candacia truncata* (Dana). 42, fourth and fifth thoracic segments and abdomen, left lateral view, female, showing cement mass attached to genital segment; 43, 44, unlike fifth feet, female, from same specimen; 45, fifth foot, female, with serrated external spinous processes, from another specimen.

NOTES ON TWO OTHER SPECIES

Candacia truncata (Dana)
Figs. 42–45

Candace truncata Dana, 1849, Proc. Amer. Acad. Arts Sci., 2: 24.
Candacia truncata Giesbrecht and Schmeil, 1898, Das Tierreich, 6, p. 130; auct.
Candacia turgida Wilson, 1950, U. S. Natl. Mus. Bul. 100, 14(4): 183–184. New synonomy.

In the course of examining plankton samples we have encountered numerous individuals of a species which appears to agree with the description of *C. turgida* Wilson (1950). We believe, however, that these specimens, as well as *C. turgida,* are identical with *C. truncata* (Dana).

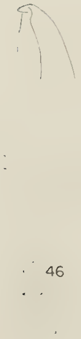
The pigmented process on the ventral side of the female genital segment (shaded portion of Fig. 42), which Wilson considered to be a protrusion of that segment, appears to be a mass of cement associated with a spermatophore. In most of the samples examined there were some females with this mass and others without. Furthermore, the mass can be removed quite easily with a needle. Tanaka (1935) presented a figure of a female *C. truncata* showing such a mass adhering to the genital segment.

Wilson's figure of the female fifth feet (1950: pl. 22, fig. 308) of his *C. turgida* apparently is not complete in detail. Dr. Thomas E. Bowman has kindly sent us a sketch of the fifth feet from one of the syntypes of this species. His sketch and the numerous fifth feet examined from our material agree in the structure of the large terminal finger. The external margin of this finger in all specimens examined and in Dr. Bowman's sketch is finely serrate along most of its length. The distolateral and two external spinous processes are, however, somewhat variable. In some specimens the distolateral spinous process has one or two relatively large teeth on the internal margin as figured by Giesbrecht (1892). One has a single external tooth opposite two internal ones; another has seven small internal teeth. In some specimens the feet are asymmetrical, being unequal in length and with unlike dentition on the distolateral spinous process. One specimen has four teeth on one foot and two on the other. In yet another, this process is toothed on one foot and smooth on the other. Figures 43–45 show some of the variations of the fifth feet of the female *C. truncata* from the central Pacific. Typical males of *C. truncata* have also been observed in our collections. Specimens of this species were obtained in the following localities: 22° 03.7′ N., 158° 40′ W. ("Hugh M. Smith" cruise 25, sta. 29, Feb. 1, 1954, 200–0 m. depth of tow); 0° 00′, 149° 36′ W. ("Hugh M. Smith" cruise 47, sta. 30, Oct. 27, 1958, surface collection). Seven females from 23° 55′ N., 157° 31′ W. ("Hugh M. Smith" cruise 30, sta. 112-2, Aug. 27, 1955, 49 m. depth of tow) have been deposited in the U. S. National Museum (USNM 102740).

Candacia norvegica (Boeck)
Figs. 46–65

The distribution of *Candacia norvegica* (Boeck) in the North Atlantic has been summarized by Farran (1948). Sewell (1932) described a variety *tropica* from the Indian Ocean. In his reports on the Carnegie and Albatross collections, Wilson (1942, 1950) recorded *C. norvegica* from many stations in the tropical and temperate Pacific Ocean. In a

FIGS. 46–65. *Candacia norvegica* (Boeck). Figures 46–62 refer to Pacific specimens; Figures 63–65 to Atlantic specimen. 46, female, lateral view; 47, abdomen, dorsal view, female; 48, lateral view of left genital spinous process; 49, lateral view of right genital spinous process; 50, 51, mandibular blades from one individual female, showing unlike basal teeth; 52, first maxilla, female; 53, second maxilla, female; 54, fifth feet, female, with two external spinous processes on each foot; 55, fifth feet, female showing three external spinous processes on one foot and two on the other; 56, male, dorsal view; 57, male, lateral view; 58, fourth and fifth thoracic segments and abdomen, dorsal view, male; 59, genital segment, ventral view, male; 60, fourth and fifth thoracic segments and genital segment, right lateral oblique view, male; 61, segments 17 through 19, right first antenna, male; 62, fifth feet, male; 63, abdomen, dorsal view, female; 64, left genital spinous process; 65, right genital spinous process. Figures 47–49 and 54 are from Pacific female 2.96 mm. total length; all others of Pacific female are from specimen 2.80 mm. total length.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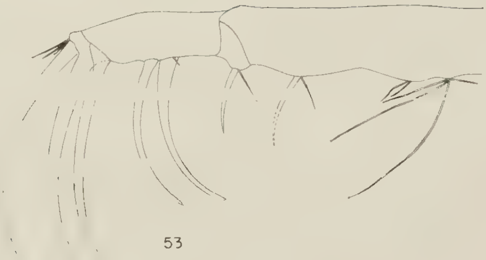
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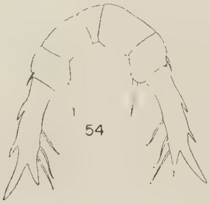
SCALES

1.0 MM. FIGS. 46, 56, 57

0.05 MM. FIGS. 48-51, 64, 65

0.1 MM. FIGS. 52, 54, 55, 60-62

0.1 MM. FIGS. 47, 53, 58, 59, 63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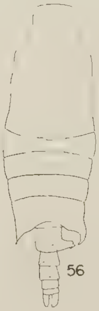
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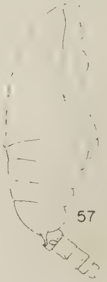
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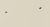
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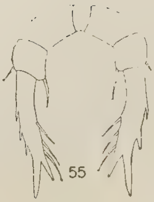
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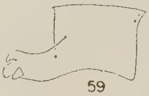
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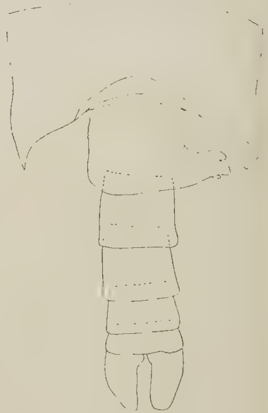
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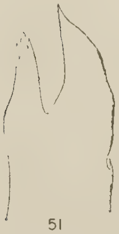
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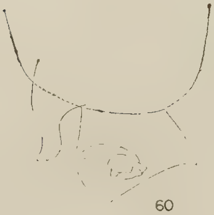
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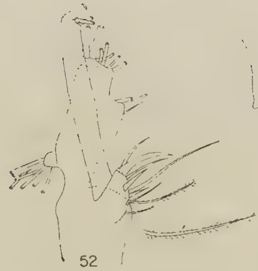
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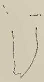
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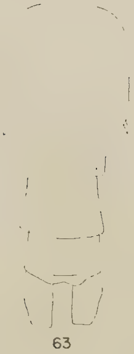
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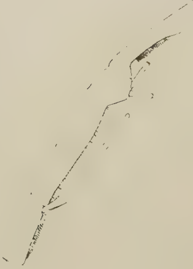
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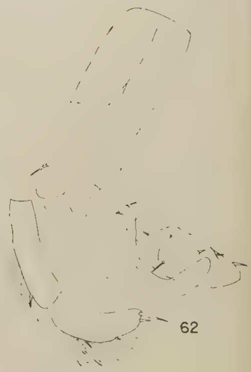
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TABLE 2
COMPARISON OF FEMALE *Candacia norvegica* FROM GEORGES BANK, THE PACIFIC, AND VARIETY *tropica*

SOURCE	TOTAL LENGTH[*] (mm.)	CEPHALOTHORAX–ABDOMEN RATIO[*]	ABDOMEN RATIO = 100 SEGMENT NUMBER			
			1	2	3	Furca
Georges Bank (USNM)	3.24	2.89:1	45	24	18	13
Pacific	2.96	2.66:1	45	24	17	14
Pacific	2.80	2.83:1	44	22	19	15
Variety *tropica* (Sewell, 1932)[†]	2.28	2.92:1	43	25	19	13

[*] Includes telescoped portion of abdominal segments of the specimens from Georges Bank and from the Pacific. Sewell's data used for *tropica.*

[†] Sewell apparently reversed the figures for the ratio of the anal segment and furca. Measurement of his figure of the abdomen shows that the length of the anal segment exceeds that of the furca.

recent paper, Fleminger and Bowman (1956) have reported that Wilson's determinations were incorrect and that *C. norvegica* was not present in any of the Carnegie and Albatross material in the U. S. National Museum. The only other mention of this species from the Pacific appears in Tanaka's (1953) list from the Izu region off southern Japan. Because no description or figures have been given of Pacific specimens and because of the apparent rarity of the species in that ocean, we are including a description based on two females and one male collected in the central North Pacific. These specimens were collected at 37° 43.9′ N., 165° 0.5′ W. ("Hugh M. Smith" cruise 25, sta. 13, Jan. 24, 1954, 200–0 m. depth of tow, 2 females and 1 male) and have been deposited in the U. S. National Museum (USNM 102741).

We have compared our specimens with Atlantic *C. norvegica* collected south of Georges Bank (northwest Atlantic) and loaned to us by the U. S. National Museum, with Sewell's description of *tropica,* and with Sars' (1903) redescription of *C. norvegica* based on specimens from the Norwegian Sea. Differences in the details of the lateral spines of the female genital segment were found. Sars implied in his description that these spines are simple and single pointed. Variety *tropica* Sewell is stated to have bifid spines on both sides. Our Pacific specimens agree with *tropica* in this respect, but the spines are somewhat smaller (Figs. 48, 49). The Georges Bank specimen examined by us has a slightly bifid tip on the left spine and a simple spine on the right (Fig. 64). Furthermore, Sars stated that the genital segment is perfectly symmetrical, but in the specimens from the Pacific (Fig. 47) and Georges Bank (Fig. 63) and in *tropica,* the left spine is larger than the right. We believe that the size and detail of these spines is variable and may be of little diagnostic value. Table 2 gives the total length, cephalothorax–abdomen ratio, and abdominal segment ratios of the specimen from Georges Bank, Pacific specimens, and Sewell's variety *tropica.*

The structure of the female fifth feet presents some variation among specimens from the Pacific and Georges Bank, Sewell's *tropica,* and Sars' description. Sewell stated that the fifth feet of *tropica* were unlike *norvegica* in that there are two rather than three "spines" on the outer margin of the distal segment, but Sars (1903) mentioned that this margin may have two or three small "denticles." Of our two Pacific specimens, one has two spinous processes on each foot (Fig. 54), and the other has two on one foot and three on the other (Fig. 55). The Georges Bank specimen has two outer spinous processes on each foot. It appears that this is a variable characteristic. In *tropica* the two terminal fingers of the fifth feet are equal, but in all others examined or described the length of the outer is about twice that of the inner finger.

Sars stated that the points on the corners of the fifth thoracic segment diverge in dorsal view, but in all other specimens and descriptions examined by us these points point straight caudad.

The male from the Pacific (Figs. 56–62) agrees closely with the Georges Bank specimen and with the description given by Sars. The total length of our specimen is 2.68 mm. and that of the Atlantic specimen is 3.23 mm.

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3. CAUSES OF MAJOR VARIATIONS IN THE CATCH OF THE PACIFIC SARDINE, *Sardinops caerulea* (GIRARD)[1]

From its position as one of the world's largest
heries, the Pacific sardine fishery decreased by an
ler of magnitude in both area and landings.

This decline cannot be shown, directly or indirect-
to be attributable to the fishery. Rather, the
line was probably associated with the effects of
environment upon year-class size.

A model which is consonant with the features of
dine biology and the fishery and which offers an
planation of the decline is:

1. Sardines which support the United States and
nadian catch are produced off southern California
d central Baja California;

2. those produced off southern California migrate
far north as British Columbia, support the fishery
re, and contribute to the fisheries at San Francisco,
nterey, and San Pedro;

3. those produced off central Baja California mi-
ate as far north as central California and contri-
te to the California fisheries, especially at San
dro;

4. lack of spawning success on the southern California spawning grounds since about 1943 could account for the observed changes in the fishery;

5. the postulated lack of spawning success off southern California is attributed to the below average temperature regime, which has delayed spawning by one or two months;

6. below average temperatures are associated with an upwelling regime and above average temperature with an advection regime;

7. under the upwelling regime, it is suggested that the sardine is unable to compete successfully with the anchovy.

JOHN C. MARR
U. S. Bureau of Commercial Fisheries
Honolulu, Hawaii

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The Application of Paper Chromatography in Identifying Tuna Larvae

SPECIAL SCIENTIFIC REPORT—FISHERIES No. 337

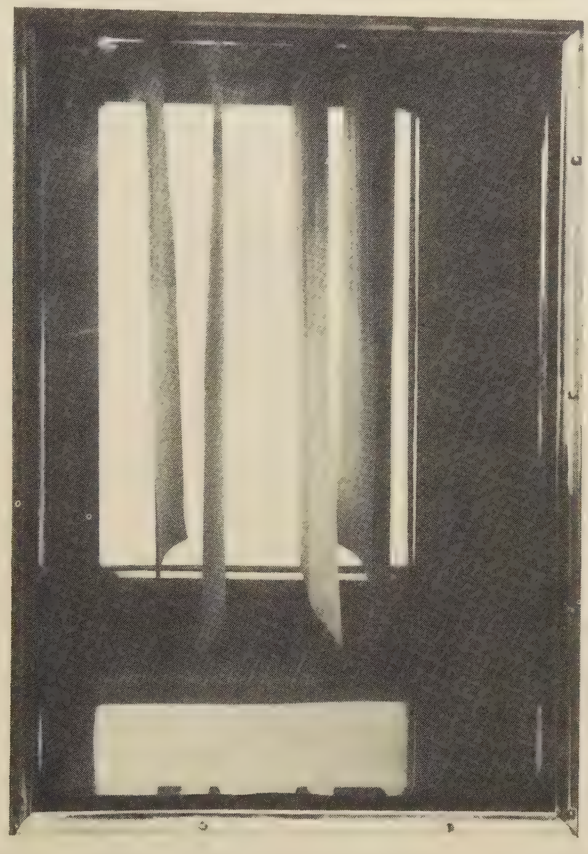
UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

United States Department of the Interior, Fred A. Seaton, Secretary

Fish and Wildlife Service, Arnie J. Suomela, Commissioner



THE APPLICATION OF PAPER CHROMATOGRAPHY IN IDENTIFYING TUNA LARVAE

By

Walter M. Matsumoto
Fishery Research Biologist
Honolulu Biological Laboratory
U. S. Bureau of Commercial Fisheries
Honolulu, Hawaii

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WASHINGTON: January 1960

ABSTRACT

In order to seek a quicker and easier means of identifying larvae of various species of tunas, experiments in paper partition chromatography were attempted. In this initial attempt the tests were limited only to determinations on the free amino acid content in the muscle tissue of these fishes. The results suggest that paper chromatographic technique has possible utility as a taxonomic tool for adult tunas. For the larvae, however, the results were rather inconsistent. It is believed that these inconsistent results were due to inadequate application of the technique rather than to failure of the technique itself.

CONTENTS

Page

Introduction. 1

Material. 2

One-dimensional chromatograms. 2

  Procedure 2

  Results. 3

Two-dimensional chromatograms. 4

  Procedure. 4

  Results. 4

Discussion and conclusions. 6

Summary. 8

Bibliography. 9

ILLUSTRATIONS

FIGURE Page

Frontispiece: Chromatograms being developed in chromatocab

1. One-dimensional chromatograms of adult tuna samples developed in two different solvents. 3

2. One-dimensional chromatograms of adult and larval samples of two species of tuna developed in n-butanol:methylethylketone:ammonia:water. 4

3. Two-dimensional chromatogram of adult little tunny. 4

4. Two-dimensional chromatogram of adult albacore. 5

5. Two-dimensional chromatogram of adult bigeye. 5

6. Two-dimensional chromatogram of adult yellowfin 6

7. Two-dimensional chromatogram of adult skipjack. 6

8. Two-dimensional chromatogram of adult bigeye run in reverse order of solvents . . . 7

9. Two-dimensional chromatogram of adult yellowfin run in reverse order of solvents. . 7

10. Two-dimensional chromatogram of larval yellowfin. 8

11. Two-dimensional chromatogram of larval skipjack 8

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Walter M. Matsumoto
Fishery Research Biologist
Honolulu Biological Laboratory
U. S. Bureau of Commercial Fisheries
Honolulu, Hawaii

The species identification of larval and postlarval tunas has constituted an important segment of the research program of the Bureau of Commercial Fisheries, Honolulu Biological Laboratory. The usual method of identifying the larger juveniles and tracing certain diagnostic characters through a decreasing size series to the smallest available larva has been employed on some species with general success (Matsumoto, 1958; 1959). However, the identification of the younger larval stages becomes increasingly difficult as smaller and smaller larvae are examined. At the very earliest stages of development, it may be impossible to distinguish one species from a closely related one. To complicate matters further, there are a number of species of tunas such as bigeye (Parathunnus sibi), albacore (Thunnus germo), bluefin (Thunnus thynnus, and Thunnus maccoyi), dogtooth (Gymnosarda nuda), whose larval and postlarval forms have not been identified positively. In an attempt to find a faster and easier method of identifying some of these larvae, techniques employed in other fields of research were reviewed. One method which was considered worthy of investigation was that of paper chromatography.

Paper chromatography is an important technique used in the identification of chemical compounds. Its merit, apart from simplicity, is its extreme sensitivity, a small amount of a substance being easily detected under suitable conditions. Paper chromatography may be either one- or two-dimensional (for details, see Block, Le Strange and Zweig, 1952; Williams, 1954). In one-dimensional tests a sample of the solution to be analyzed is placed near one end of a strip of filter paper and that end of the paper is dipped into an appropriate solvent. Capillary action draws the solvent through the paper and through the spot where the sample solution had been applied. Each substance in the sample will move along with the solvent at a unique rate, such that all the substances in the sample will occupy a distinct position somewhere along the path of flow of the solvent. The rate of movement of each substance, and therefore the final position attained by each substance, in a given time, depends upon its solubility in the particular solvent used. Upon drying and treating the paper with a suitable indicator, the various substances appear as visible, colored spots. Substances within the sample which cannot be clearly separated or identified in one-dimensional chromatography may sometimes be separated by the two-dimensional method. In this a large sheet of paper, about 20 x 20 inches, is used. The paper is dried after the application of the first solvent and the side nearest the sample is then dipped into a second solvent. Upon completion of the development, the paper is dried and treated with a suitable indicator.

Initially the purpose of this study was (1) to explore the usefulness of paper chromatography in identifying the larvae and postlarvae of several species of closely related tunas, especially yellowfin (Neothunnus macropterus), bigeye and albacore, and then if possible, (2) to apply the method under field (shipboard) conditions.

On the assumption that the free amino acids in the muscle tissues of fishes are hereditary, the chromatograms obtained from samples of adults and larvae of the same species should show similarities. The plan of work followed, therefore, was first to determine the differences or similarities among the various species of adult tunas available for study; second, to compare the larval and adult samples; and third, to determine species differences among the tuna larvae.

Ordinarily in chromatographic work the concentration of specific substances in the samples tested would be determined by quantitative analysis. This was not considered worthwhile in this study, since, initially at least, I was interested only in determining if there were significant differences in the general chromatographic patterns of the amino acids found in tuna flesh. Consequently, possible variations due to locality of capture, between sexes, changes in amino acid complex with length of time the fish were kept in storage, and other variables were not considered.

The chemical analysis was done at the Hawaiian Sugar Planter's Association (HSPA) Experiment Station, where the paper chromatographic technique is regularly used. I wish to thank Dr. J. H. Payne, Principal Technologist at the HSPA Experiment Station, for the use of laboratory facilities and materials; Dr. Chen-Chuan Tu, Senior Technologist, for valuable technical advice; and chemists Richard M. Okamoto and George Akatsuka for aid in running the chromatograms. I am also grateful to Tamotsu Nakata, Scientific Illustrator at the Honolulu Biological Laboratory, for preparing the figures.

MATERIAL

Samples of fresh muscle tissue of adult tunas captured in Hawaiian waters were obtained at the Honolulu fish market and from the Bureau of Commercial Fisheries research vessel Charles H. Gilbert. It was not possible to collect uniformly fresh samples, since those obtained at the market had been kept chilled from 1 to 10 days, whereas those taken on the research vessel were frozen immediately after the completion of fishing operations. Samples from the fish market included yellowfin, bigeye and albacore, and those from the vessel consisted of skipjack (Katsuwonus pelamis) and little tunny (Euthynnus yaito). Two species of frigate mackerels (Auxis thazard and A. thynnoides), which were taken on November 30, 1957 from the Bureau's research vessel, John R. Manning, and kept frozen for about 8 months, were also used in this study. Fresh samples of these two species were not immediately available.

Samples of tuna larvae were obtained from zooplankton collections taken by the Gilbert working in Hawaiian waters, and from another of the Bureau's research vessels, Hugh M. Smith working in Hawaiian and equatorial waters. The zooplankton samples were frozen aboard the vessels immediately upon capture. At the laboratory, the samples were thawed and tuna larvae and postlarvae were sorted out in a bath of ice water under a dissecting microscope. The larvae were refrozen for later use. Because they could be readily identified visually, only yellowfin and skipjack larvae were employed in this preliminary work. These larvae measured 4.5 to 10.2 mm. in total length.

Solvents used in the experiments were some of those which had been used successfully by other workers in separating amino acids. They were (1) 80 percent solution of phenol in water, (2) m-cresol: acetic acid:water (48:2:50), (3) n-butanol:methylethylketone: 17 N ammonia: water (5:3:1:1) and (4) n-butanol:acetic acid:water (4:1:5). A 0.1 percent solution of ninhydrin in 95 percent ethanol was used as the indicator solution to visually detect the amino acid spots on the paper.

Whatman No. 1 filter paper was used throughout the experiments. For one-dimensional chromatograms, 7 x 22-inch sheets of paper were used. For two-dimensional work, 18 1/2 x 22-inch sheets were used.

ONE-DIMENSIONAL CHROMATOGRAMS

Procedure

In one-dimensional chromatography the samples were placed about 1 inch apart in a row near one end of the filter paper. They were allowed to dry at room temperature and the amino acids were separated in a descending chromatogram by dipping the end of the paper bearing the samples into a suitable solvent. In order to intensify the color of the various amino acids present, the paper was heated in a convection oven at about 80°C. for 10 to 15 minutes after applying the indicator solution. The outline of each acid spot was then marked with pencil.

The first series of chromatograms was intended to define sample size and solvent appropriate to the clear separation of amino acids present in adult muscle tissue. Phenol was used as the solvent for the initial tests which consisted of 10 samples. Two of these samples consisted of small pieces of muscle tissue (approximately 8 mm.^{3}) pressed directly onto the filter paper. Although excess tissue was removed, considerable streaking occurred and there was no separation of the acids. Samples of fluid which were squeezed from muscle tissue varying in size from 1 to 30 µl. were also tested. Of these, only the 1 µl. sample appeared promising. Therefore, further tests were made on this sample size with a sample from each of 6 species of tunas. The chromatograms showed some streaking, and the separation of the amino acids was indistinct.

A second solvent, m-cresol:acetic acid: water, was tried with a 1 µl. sample from each of the previous 6 species. Reasonably good separations were obtained, but the spots were not well defined and were of the type known as "comets."

A third solvent, a solution of n-butanol: methylethylketone: 17 N ammonia:water, also was tested as before. With this solvent, excellent separation was obtained from samples of all of the species. Larvae of two species of tunas, skipjack and yellowfin, measuring from 5.5 mm. to 10.5 mm. were used for these tests. Four skipjack samples consisting of 1, 2, 3 and 5 larvae, and three yellowfin samples consisting of 1, 2 and 3 larvae were tested. In addition, samples of muscle tissue fluid from adults of skipjack and yellowfin were used as controls. Each larval sample was mashed on the filter paper with the end of a glass rod, and the tissue was removed to prevent streaking around the point of application.

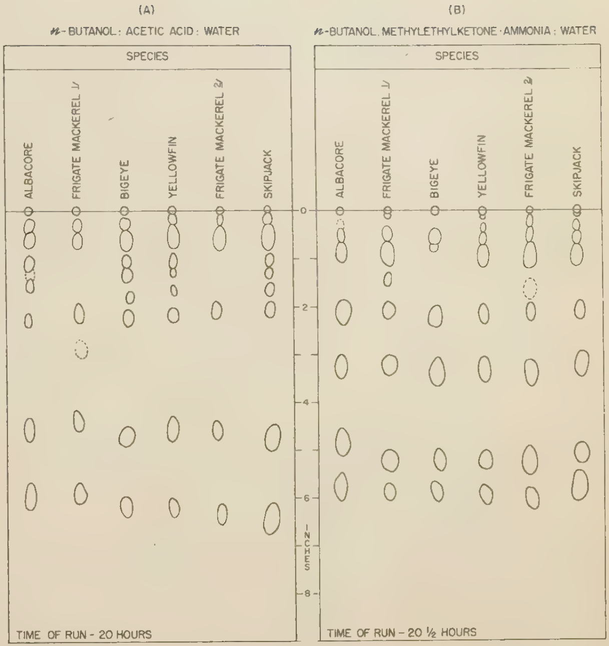
In addition to the three solvents mentioned, n-butanol:acetic acid:water was also tried and excellent separation was obtained with them. Of the four solvents used, the two n-butanol solutions provided the best results, m-cresol was fair, and phenol was not satisfactory.

Another series of chromatograms was prepared in order to determine the proper size of the larval sample required for clear separations. In this series n-butanol:methylethylketone: 17 N ammonia:water, which had proved successful for the adult samples, was used as the solvent. There was good separation in the 2- and 3-larvae samples, but only faint traces were obtained from samples with 1 and 5 larvae. Thus, it was decided that a sample size of about 3 larvae was adequate.

Results

Interesting results were obtained in the chromatograms developed in the two n-butanol solvents (fig. 1). In solvent A (n-butanol:acetic acid:water) it was possible to distinguish the adults of the two frigate mackerels from the other tunas by the smaller number (5) and position of the spots. However, the two species did not differ much from each other. It is not possible to state how much of this difference was due to the long period (about 1 year) the frigate mackerels had been kept frozen. Of the other species, albacore showed 7 spots and was easily separated from bigeye, yellowfin and skipjack, which had nearly identical patterns of 8 spots each. All of these samples, except skipjack were obtained from the fish market.

Somewhat different results were obtained when the same samples were run in solvent B (n-butanol:methylethylketone:ammonia:water). The two frigate mackerels had more spots (8) than in solvent A. The positions of the spots differed, indicating the presence of additional amino acids not shown by solvent A. Of the other species, bigeye and albacore had fewer spots (6 and 7, respectively) and their positions differed, but there was no change in the number of spots in yellowfin and skipjack.



1/ AUXIS THYNNOIDES
2/ AUXIS THAZARD

Figure 1.--One-dimensional chromatograms of adult tuna samples developed in two different solvents.

Considering the number and location of amino acid spots revealed with the two solvents, it is possible to differentiate the adult albacore and bigeye from the others. The two frigate mackerels can be distinguished from the other species by the smaller number of spots in solvent A and from each other by the position of the spots in solvent B. The yellowfin and skipjack can be distinguished from other species, but not from each other.

Chromatograms of the larvae of yellowfin and skipjack were generally comparable to that of the adults, but exhibited wide variations in the number of spots obtained. Five out of 9 sample applications (1- and 3-larvae samples) produced good separation, showing 7 or 8 spots, 2 sample applications (1-larva samples) produced no spots and 2 sample applications (1- and 5-larvae samples) produced 3 or 4 spots. In all instances where a sufficient number of spots (8) were obtained, the positions of the spots generally coincided with those of the respective adult traces (fig. 2). However, inasmuch as the adults of these two species yielded similar results, it was not surprising to find no significant difference in the larval chromatograms of the two species.

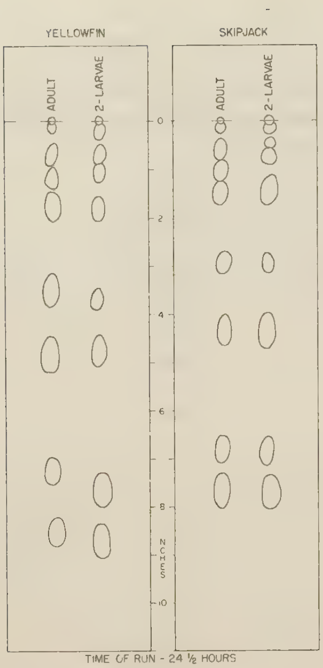


Figure 2.--One-dimensional chromatograms of adult and larval samples of two species of tunas developed in n-butanol:methylethylketone:ammonia:water.

TWO-DIMENSIONAL CHROMATOGRAMS

Procedure

In two-dimensional chromatograms the sample to be analyzed was placed in one corner of a large (18 x 22 inches) sheet of filter paper. The end of the paper nearest the sample was placed in the first solvent until the solvent front had descended to the opposite edge. After drying, an edge of the paper adjacent to the sample was dipped into a second solvent and allowed to develop as in the first instance. The paper was then dried and treated with the indicator solution.

Because successful separation of the amino acids was obtained with n-butanol:methylethylketone: 17 N ammonia:water and n-butanol: acetic acid:water in one-dimensional chromatography, these solvents were used in the order mentioned. The samples of adults were prepared by squeezing out the muscle fluid by hand. Larval samples consisted of whole tuna larvae which were squeezed directly on the paper with a glass rod. Samples from adults of 5 species of tunas (yellowfin, bigeye, albacore, skipjack and little tunny) and the larvae of 2 species of tunas (yellowfin and skipjack) were developed for 21 to 24 hours in each solvent. The amount of sample used was 10 µl. of muscle tissue fluid from each of the adults and 2 to 7 larvae of each of the latter two species.

Results

The results of the two-dimensional chromatograms were not always satisfactory and varied considerably from one experiment to another. In many instances the variations were extreme, from 0 to 11 or 12 spots, even among samples taken from fish of the same species. Part of these variations were probably due to the inexact manner in which the samples had been prepared. The comparisons discussed here are based only on those chromatograms which yielded the maximum spots per species, and may be somewhat arbitrary. Nevertheless, they give us some idea whether this method is applicable in species identification of the tunas.

Figures 3-7 show five of the better traces obtained with samples from adult tunas. Some differences were evident between little tunny, albacore, bigeye and skipjack, but differences between bigeye and yellowfin could not be determined, since the trace of the latter species showed some streaking and the separation of the spots was not sufficiently clear.

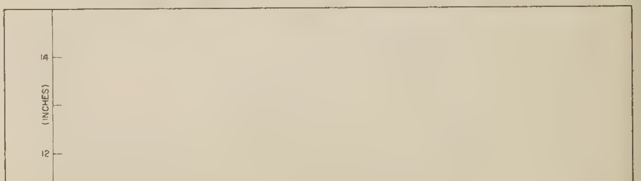

14
12
10
8
6
4
2
(INCHES)
SECOND DIRECTION : n-BUTANOL : ACETIC ACID : WATER - 24 HOURS
START
2
4
6
8
10
(INCHES)
FIRST DIRECTION : n-BUTANOL : METHYLETHYLKETONE : AMMONIA : WATER - 24 HOURS

Figure 3.--Two-dimensional chromatogram of adult little tunny.

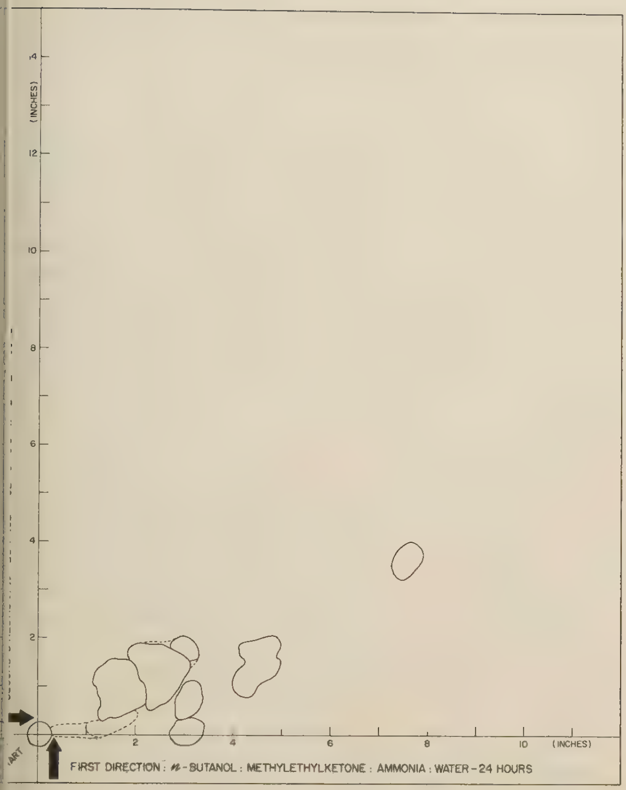


Figure 4. --Two-dimensional chromatogram of adult albacore.

A second testing of the bigeye and yellowfin samples produced better separation of the spots (figs. 8 and 9). In this instance, the order of solvents was inadvertantly reversed, but it is not believed that this had any adverse effect on the chromatograms. Both species showed slightly different patterns than those run in the original order of solvents. However, the differences, if any, between the two species were insignificant.

Some discrepancy is noted in the number of spots obtained with identical solvents between the one- and two-dimensional chromatograms, i.e., the two-dimensional chromatograms contained less spots in each of the solvents than the one-dimensional chromatograms run in identical solvents. This discrepancy could perhaps be due to difference in the time of runs (1 month apart) between the two tests. There is also the possibility that some of the amino acids separated in one solvent may have been lost in the other solvent in the two-dimensional tests. Because the amino acids were not identified, it is not possible to say whether the acids lost in each of the two dimensions were of the same type for all of the samples. However, inasmuch as this would involve a specific action between solvent and acid, it is logical to assume that identical acids were lost by all of the species. If so, this discrepancy should not affect the final results.

Both good and poor results were obtained from the samples of larval tunas. In the case of yellowfin (fig. 10), no trace was obtained with samples of less than 5 larvae and even with this number, the sample size seemed to be too small. Perhaps the use of more larvae would have given better results, but the supply of larval yellowfin was depleted at this stage of the investigation and further tests were not possible.

In the case of skipjack (fig. 11), however, better results were obtained. The figure shows the chromatogram of a sample of 7 larvae, their sizes ranging from 4.5 to 8.0 mm. Although not all of the amino acids shown by the adults were obtained from the larvae, a sufficient number was developed to show some similarity in the overall patterns of the dominant amino acids.

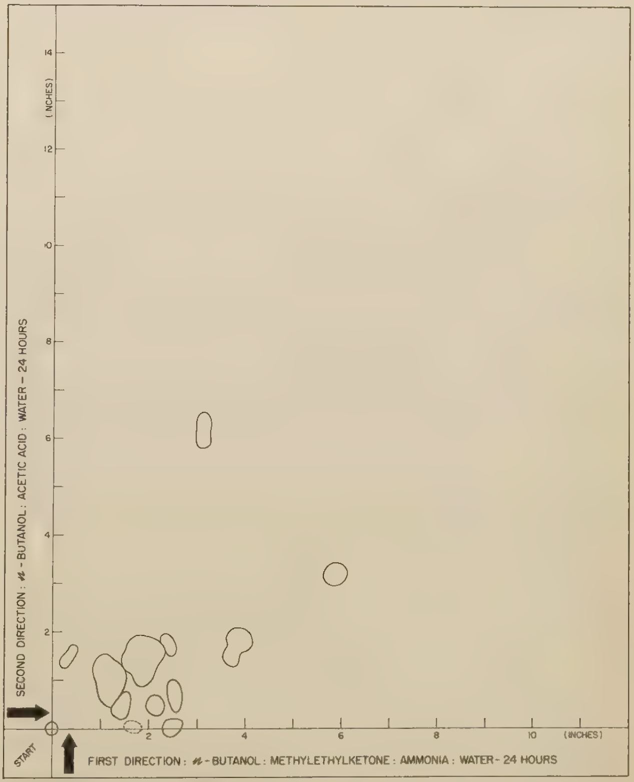


Figure 5. --Two-dimensional chromatogram of adult bigeye.

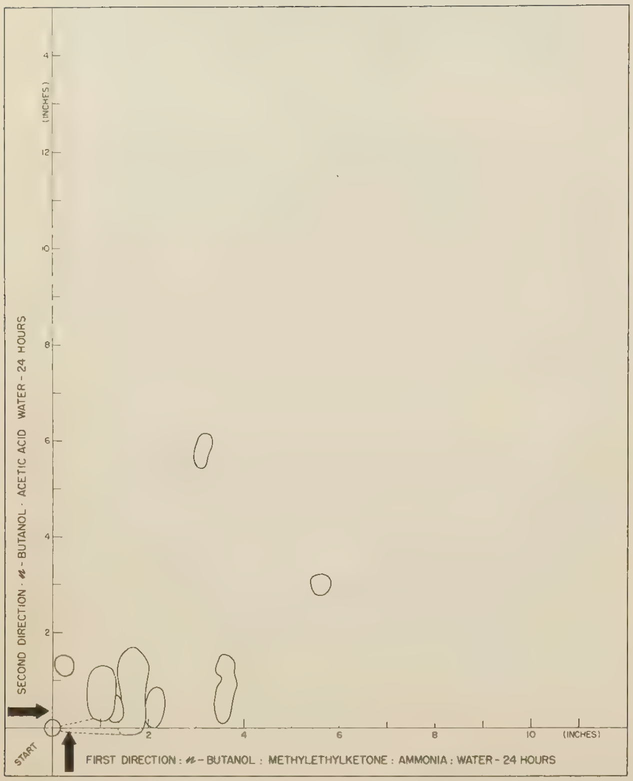


Figure 6. --Two-dimensional chromatogram of adult yellowfin.

DISCUSSION AND CONCLUSIONS

These experiments provided valuable information concerning the use of chromatographic technique in the species identification of some of the tunas. It was found that adult samples of the same species of tuna developed one-dimensionally in different solvents resulted in dissimilar chromatograms. This was particularly noticeable of the albacore and bigeye samples. Although yellowfin and skipjack samples developed in two different solvents showed no difference in the chromatograms, it is believed that trials with other solvents would reveal a suitable solvent capable of producing different chromatograms between these two species. Similarly, suitable solvents also could be sought for the two frigate mackerels and other species of tunas not mentioned. If successful, one-dimensional chromatography might be a useful taxonomic tool for adult tunas.

The same cannot be said with equal assurance about larval identification because larvae of only two species (yellowfin and skipjack) were tested. However, one encouraging observation, the general similarity of adult and larval chromatograms, was noted in the results of the larval tests.

As expected, adult samples developed successfully in two-dimensions yielded more spots than those developed in only one-dimension, and differences in the position of the spots were more pronounced among most of the species. Only two out of the six species tested could not be distinguished, since chromatograms of yellowfin and bigeye samples appeared identical. Perhaps the use of other solvents may provide visible differences between these two species.

Results of larval samples of yellowfin and skipjack were rather inconsistent. However, they do not preclude the usefulness of this technique in taxonomic studies. Part of the inconsistency could have been due to inadequate methods of application which can be remedied. There is some encouragement in the fact that, of the better results obtained with skipjack larvae, some similarity in the general distributional pattern of the more prominent amino acids were evident.

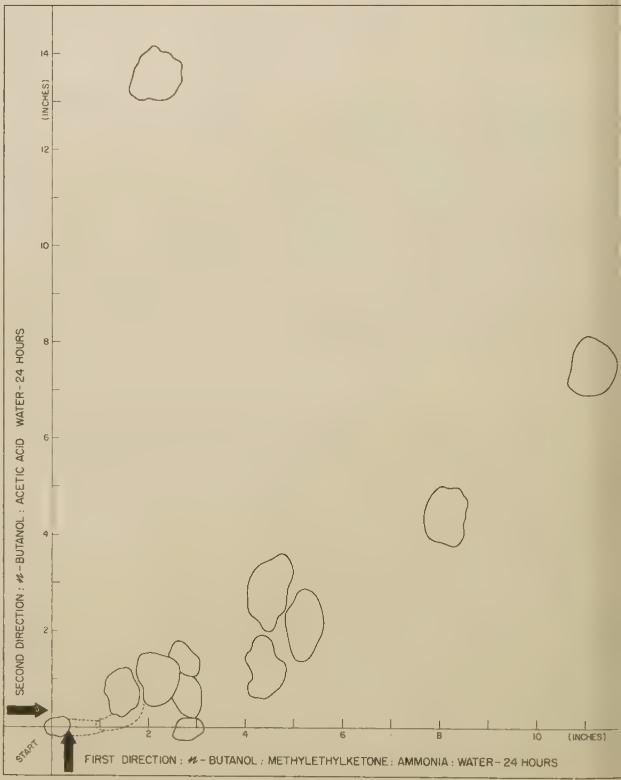


Figure 7. --Two-dimensional chromatogram of adult skipjack.

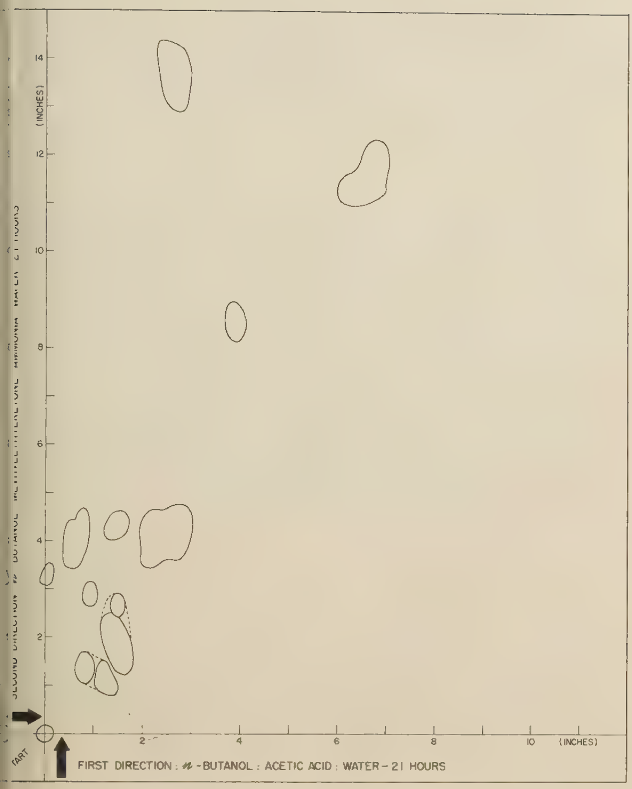


Figure 8. --Two-dimensional chromatogram of adult bigeye run in reverse order of solvents.

The only definite and consistent difference between adult and larval samples in both one- and two-dimensional chromatograms was the presence of a dark greenish-brown spot in all the adult samples. This contrasted with the purplish color exhibited by all other amino acids. The spot, which was identified as aspartic acid from chromatograms of 14 known amino acids developed in identical solvents as the test samples, was not found in any of the larval samples. Inasmuch as adult samples of all the species tested showed this particular amino acid, it is believed that this acid reflects growth rather than species difference.

There are several hypothetical reasons which may account for the inconsistency in the results of the larval samples. One of these is the probable reduction of amino acid concentration in the larvae owing to leaching. Larvae used as samples had been frozen and thawed repeatedly from the time they were first captured to the time they were tested. Inasmuch as the free amino acids found in animal tissues are water soluble, it is reasonable to believe that much of the amino acids had been lost during the thawing processes.

Another reason is the possibility that both leaching and partial decomposition of the amino acids still remaining in the tissue may have occurred in larvae which had been dead prior to capture. That such incidence of mortality among the larvae prior to capture is occasionally quite extensive in restricted localities was shown by Strasburg (1959), who found as much as 99 percent mortality in the larvae of frigate mackerel (Auxis sp.) at one locality.

There is also a remote possibility that part of the inconsistency could have been the result of variations in the amino acid complex caused by changes in the diet of the larvae. Evidence of such variations in fish was found by Farris (1958) in experiments with controlled feeding of a sardine (Sardinops caerulea). Whether dietary changes of such magnitude as to cause variations in the amino acid complex of tuna larvae do occur in nature, or the effect this change has on the survival of the larvae is not yet known. However, inasmuch as the possibility does exist, such factors as this must be considered.

In view of the limitations in the experimental design and the failure in obtaining equally fresh adult samples of all the species tested,

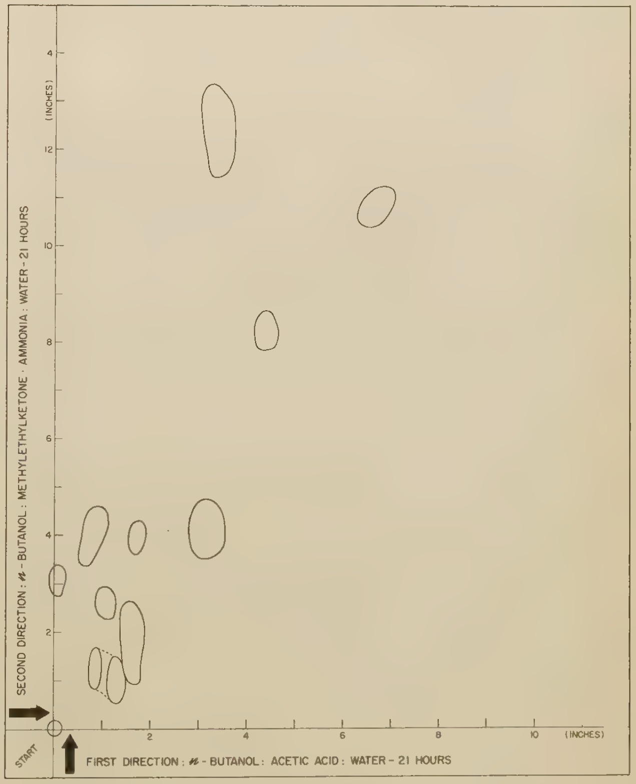


Figure 9. --Two-dimensional chromatogram of adult yellowfin run in reverse order of solvents.

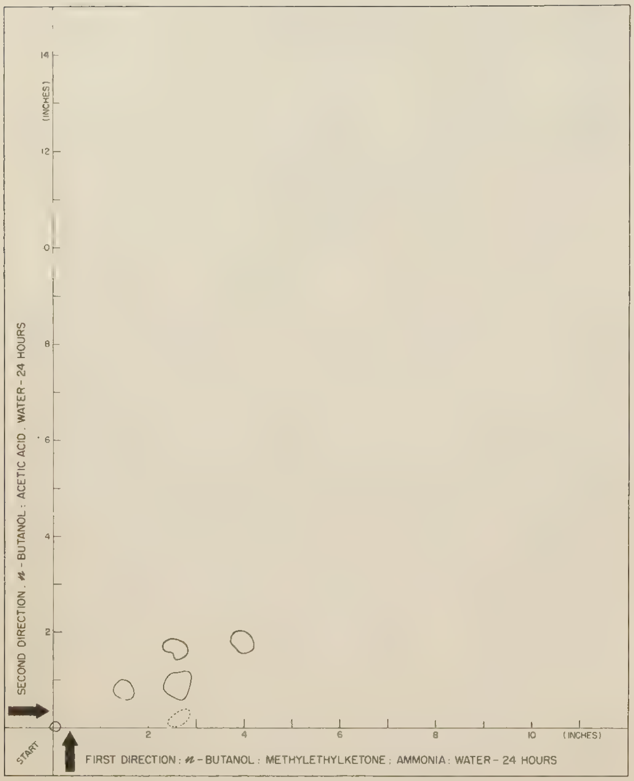


Figure 10. --Two-dimensional chromatogram of larval yellowfin.

the author feels that any conclusion on the use of the technique in species identification of tunas would be premature. The technique is not without promise, however, as was noticed by the difference in positions of spots in the two frigate mackerels, which had been captured at the same time and kept frozen an equal length of time. Also, the close resemblance between adult and larval skipjack, both of which had been frozen immediately upon capture, is significant.

Comparing the number of spots shown by adult species other than skipjack with those developed with fresh-frozen skipjack, it is believed that either the changes due to proteolytic enzyme reaction may not have been as important as suspected, or that the suspicion that these fish had been taken at such widely differing time as to cause noticeable changes in the amino acid complex could have been unfounded. If so, the data obtained are certainly encouraging.

SUMMARY

1. Both one- and two-dimensional chromatography on paper were attempted: first, to see if the various species of adult tunas possessed characteristic compositions of free amino acids; second, to determine if the known tuna larvae possessed the same free amino acids as their respective adults; and third, to develop, if possible, a simplified shipboard technique.

2. Instead of trying to identify each specific amino acid found in the muscle tissue of these fish, emphasis was placed upon seeking characteristic differences in the overall chromatographic patterns of the amino acids among the various species of tunas tested.

3. Samples consisted of small bits of muscle tissue (approximately 8 mm.^{3}) and minute quantities of fluid squeezed from muscle tissues. They were placed directly upon the filter paper.

4. Four different solvents were tested, with n-butanol:acetic acid:water in a ration of 4:1:5 and n-butanol:methylethylketone: 17 N ammonia:water in a ratio of 5:3:1:1 showing the best results in both one- and two-dimensional chromatograms. All experiments were made on Whatman No. 1 filter paper.

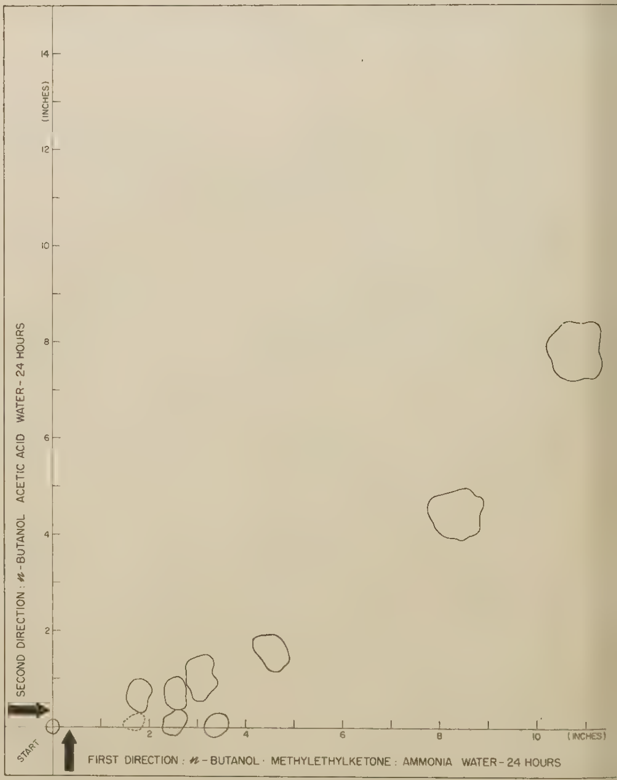


Figure 11. --Two-dimensional chromatogram of larval skipjack.

5. Giving due consideration to the fact that the time of capture was unknown for all of the samples and that the treatment of the samples had not been uniform, it is suspected that this technique may have useful possibilities in taxonomic studies of the adults.

6. Chromatograms of the larvae, in repeated runs of samples of the same species, showed varying results. The inconsistencies in these results may, in part, have resulted from the loss of free amino acids from the larvae due to leaching after death, prior to their capture, or if taken alive, to the repeated freezing and thawing they were subjected to while they were being segregated from the rest of the plankton. Although the amount and effect of decomposition of the amino acids in the larval samples were not investigated, this possibility cannot be ignored.

7. The author feels that any conclusion regarding the use of chromatographic technique, based on the present experiments, is premature. Nevertheless, he believes that methods of applying this technique to taxonomic' studies of adult and larval tunas can be developed.

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Notes on the Hawaiian Frigate Mackerel of the Genus *Auxis*

WALTER M. MATSUMOTO

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April, 1960

Reprinted from PACIFIC SCIENCE, *vol. XIV, no. 2, April, 1960*

Notes on the Hawaiian Frigate Mackerel of the Genus *Auxis*

WALTER M. MATSUMOTO[1]

A NEW DISTRIBUTION RECORD for a long-corseletted frigate mackerel of the genus *Auxis* was established on November 30, 1957, with the capture of 21 specimens in the central Pacific Ocean. These fish were taken from the same school together with five short-corseletted frigate mackerels. The catch was made from the research vessel "John R. Manning" of the Pacific Oceanic Fishery Investigations (POFI), by pole-and-line fishing, one mile offshore, two miles northwest of Cape Kaea, Lanai. Although the long- and short-corseletted *Auxis* are known from both sides of the Pacific, only the short-corseletted form has been reported heretofore from the central Pacific area.

As is the case with some of the other scombrids, the taxonomy of this genus is not very clear. Although the identity of the short-corseletted form has been well established as *A. thazard* (Lacépède 1802), the nomenclature of the long-corseletted form has been confused because of incomplete description and subsequent misnaming by other workers. It is hoped that this paper will help to clarify the nomenclature of this genus.

The long-corseletted form of the western Pacific has been identified by various names. Kishinouye (1915: 13–14) recognized two species of *Auxis* in Japanese waters, to which he ascribed the names *A. hira* and *A. maru.* The former species was described as having a short corselet which ended slightly posterior to the pectoral fin, whereas the latter was described as having a long corselet which extended to the anal fin. Under the description of the latter species, Kishinouye stated that "Bleeker's *tapeinosoma* may also be this species, but the figure and description of this species are very rough and unclear." In recent years Herre and Herald (1951: 319) and Wade (1949: 229) applied the name *tapeinosoma* to the Philippine long-corseletted form. A review of Bleeker's original description (1854: 408), however, discloses that *tapeinosoma* is definitely a short-corseletted form, for according to him the corselet ends "slightly posterior to the pectoral fins." This character agrees with the short corselet of *thazard* and *hira,* and therefore, *tapeinosoma,* as used by Herre and Herald, and by Wade, in identifying the long-corseletted species is a misnomer.

The appropriate name for the western Pacific long-corseletted species seems to be *A. thynnoides* Bleeker. Examination of Bleeker's (1855: 301) original description of the type specimen which was taken at Ternate, East Indies, and which is now in the Leiden Museum, clearly indicates that his specimen is the long-corseletted form, for he states that the corselet along the lateral line ends "far behind the pectoral fin." The writer's interpretation of Bleeker's description is confirmed by John E. Fitch (through private correspondence), who has checked the type specimen. It is apparent from the original description and from Fitch's information that *thynnoides* is the earliest available name for the western Pacific long-corseletted species. The Hawaiian form described here is identical with that from the Philippine waters and agrees well with the type specimen described by Bleeker. Consequently, it is given the name *A. thynnoides* Bleeker.

A. thazard has been described many times by previous workers. Nevertheless, in order to facilitate the comparison between this species and *thynnoides,* the descriptions of both are presented.

DESCRIPTIONS OF SPECIES

Auxis thynnoides Bleeker

Fig. 1

This description is based on 20 specimens which are now deposited at the POFI laboratory, Honolulu, Hawaii.

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[1] Fishery Research Biologist, Bureau of Commercial Fisheries, Hawaii Area, Honolulu. Manuscript received September 17, 1958.

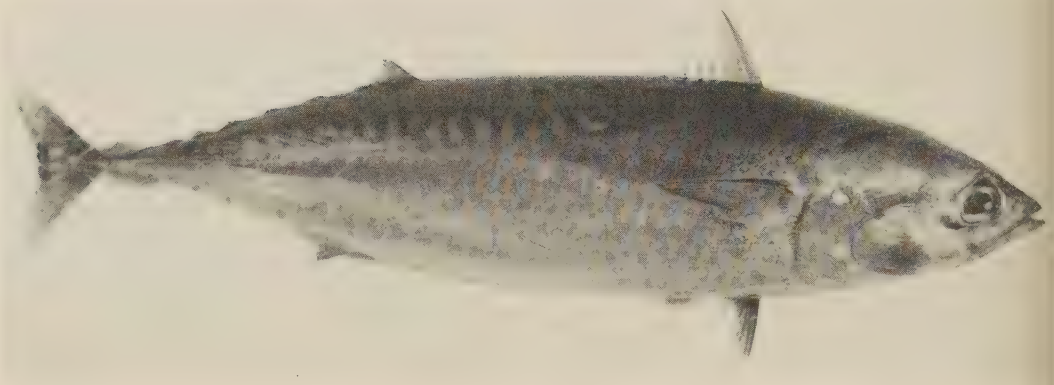

FIG. 1. *Auxis thynnoides* Bleeker.

Dorsal X–XI, 10–11, 8. Anal 12–13, 7. Gill rakers 10–11 + 1 + 32–36 = 43–48. Total length 262–290 mm.

Body robust, fusiform, almost cylindrical in cross section. Snout short, pointed. Mouth moderate; gape to slightly past anterior margin of pupil. Each jaw with single row of small, weak teeth. Palatines and vomer toothless. Dorsal fins well separated. Dorsal interspace slightly greater than half the distance between origins of first and second dorsals.

Vertebrae 20 + 19 = 39, including urostyle. First haemal arch on 8th vertebra; first closed haemal arch and first haemal spine on 21st vertebra. Haemal canal borne away from body of vertebra by pedicles [of Starks (1910: 97) = epihaemal processes of Kishinouye (1923: 460)].

Body naked, except for corselet of scales. Corselet along lateral line extends beyond vertical through posterior end of second dorsal. Corselet 16–18 scale-rows wide below origin of second dorsal fin. Lateral line more or less undulating, without any pronounced arch.

Body markings consist of 14–16 dark, nearly vertical bars over bluish background above lateral line. Bars often broken into spots. Dark continuous band over top of head and along dorsal margin of body. The band more or less uniform in width to end of second dorsal, whence it narrows posteriorly to base of caudal fin. Body below lateral line silvery white and free of markings or spots.

Auxis thazard (Lacépède)

Fig. 2

This description is based on five specimens which are deposited at the POFI laboratory, Honolulu, Hawaii.

Dorsal XI, 10–12, 8. Anal 13, 7. Gill rakers 9–10 + 1 + 28–31 = 39–42. Total length 272–283 mm.

Body robust, more or less compressed laterally. Snout short, pointed. Mouth moderate; gape to well past anterior edge of pupil. Each jaw with single row of small, weak teeth. Palatines and vomer toothless. Dorsal fins well separated. Dorsal interspace less than half the distance between the origins of the first and second dorsals.

Vertebrae 20 + 19 = 39, including urostyle. First haemal arch on 8th vertebra; first closed haemal arch and first haemal spine on 21st vertebra. Haemal canal borne away from body of vertebra by pedicles.

Body naked, except for corselet of scales. Corselet along lateral line extends posteriorly to about two-thirds the distance from the origin of first dorsal to the origin of second dorsal. Lateral line only one or two scale-rows wide beneath second dorsal origin. Lateral line more or less undulating, without any pronounced arch.

Body markings about 16 dark, oblique bars running posterodorsally and overlying bluish background above lateral line. Bars variable in number and often broken into spots. Dark continuous band over top of head and along dorsal nargin of body. The band more or less uniform n width to above tip of pectorals whence it arrows posteriorly to base of second dorsal finet. Body below lateral line silvery white and ree of markings or spots.

DISCUSSION

Several distinguishing characters are noted in he two types of *Auxis* described here. The most bvious of these is the corselet formation along he lateral line. In *thazard* the corselet narrows bruptly toward the lateral line and ends at bout two-thirds of the distance from the origin f the first dorsal to the origin of the second orsal fin. On larger specimens, 350 to 400 mm. ong, according to Wade (1949: 234), the orselet tapers less rapidly than in smaller specinens, but in no case does it extend to the level f the second dorsal origin. In contrast to this he corselet of *thynnoides* tapers very gradually nd terminates between the first and second orsal finlet. In the Hawaiian specimens the orselet is still 16 to 18 scale-rows wide beneath he origin of the second dorsal fin. In the smaller hilippine specimens, whose total lengths range etween 195 and 235 mm., the corselet beneath he second dorsal fin is from 9 to 15 scale-rows ide.

Upon examining the corselet of these specinens, it was noticed that the largest scales were djacent to the lateral line, and that the size of he scales diminished on each succeeding scale-ow away from the lateral line. From this observation and also from the previous one, that the larger Hawaiian specimens have more scale-rows than the smaller Philippine specimens, it was suspected that the width of the corselet increased with growth of the fish. An analysis of the regression of number of scale-rows on fish length (Hawaiian and Philippine material combined) yielded the equation, $Y = 0.078 \times - 4.55$, which is shown graphically in Figure 3. The highly significant regression coefficient ($b = 0.078$; $t = 12.14$, $P < 0.001$, at 19 degrees of freedom) indicates that the number of scale-rows increases as the body length does, and that therefore, the variation in corselet width between the Philippine and Hawaiian specimens represents growth rather than a species difference.

An interesting character, one which has seldom been used previously in separating the two forms of *Auxis,* is the configuration of body markings. In both species the dorsal half of the body contains a number of dark bars. Although these bars vary in number and are sometimes broken into spots, their position on the body is distinctive. In *thazard* the bars lie obliquely in a posterodorsal direction. In addition to these bars, the dorsal surface of the body is marked with a dark longitudinal band which is as wide as the interorbital space and which extends evenly from the snout to above the tip of the pectoral fin. It then tapers gradually to about the base of the second dorsal finlet. In *thynnoides,* on the other hand, the bars lie in a more

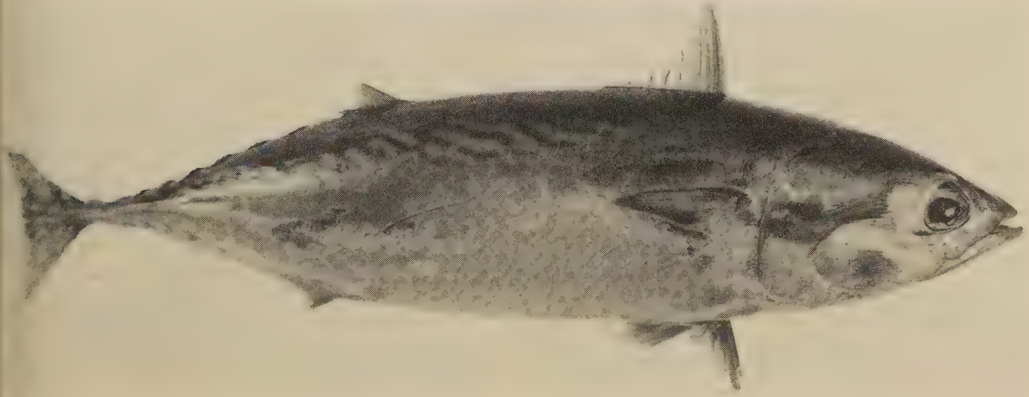

FIG. 2. *Auxis thazard* (Lacépède).

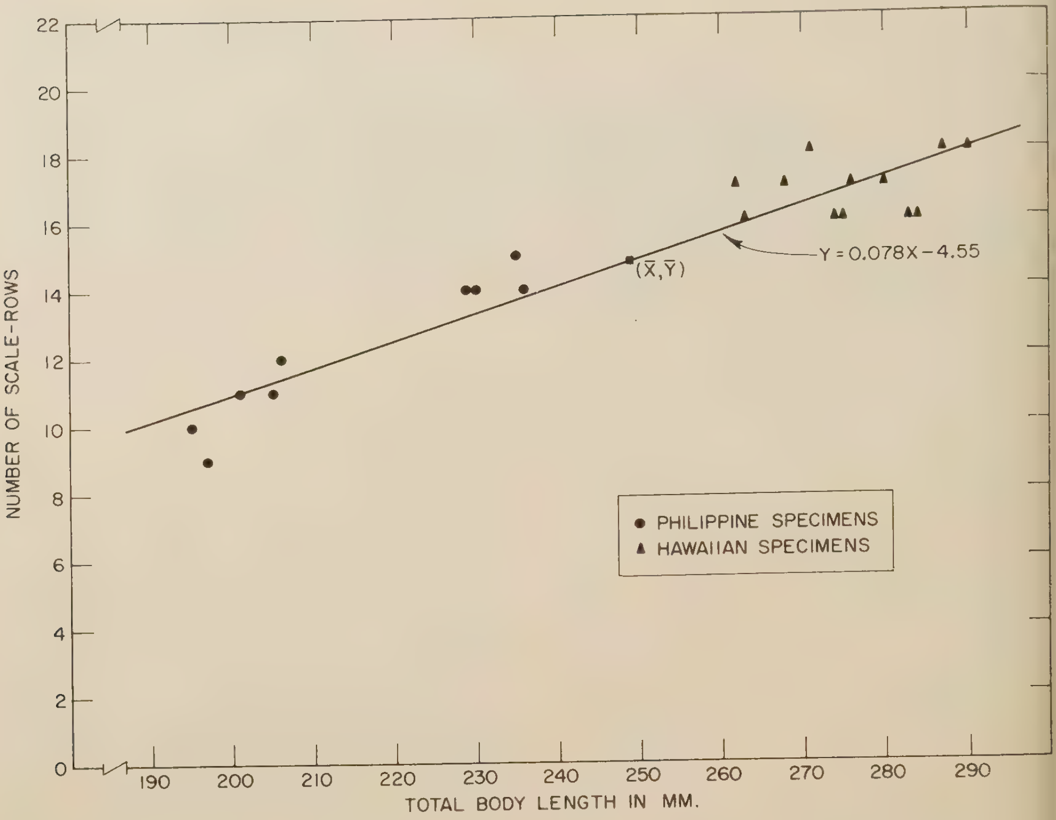

FIG. 3. Regression of the number of scale-rows on total body length of *Auxis thynnoides.*

or less vertical direction, and the dark longitudinal band on the dorsal surface of the body does not taper noticeably until it reaches the end of the second dorsal fin, whence it continues to the base of the caudal fin, tapering very gradually.

Another character often mentioned by investigators in separating the two forms of *Auxis* is the difference in the roundness of the body. In both species the ratios of body length (fork length) to body width are nearly identical (6.04 to 6.56 in *thazard;* 6.02 to 6.58 in *thynnoides);* however, the ratio of body length to body depth of *thynnoides* (4.55 to 4.98) is greater than that of *thazard* (4.32 to 4.56). Consequently, *thynnoides* appears fusiform, whereas *thazard,* because of its greater depth, appears laterally compressed. In visual comparison, this difference is so slight that it requires an unusually keen observer or one who has had practice in this observation to notice the difference.

Nearly all of the characters examined on the two species exhibit very small differences which are difficult to recognize in the field. Even the relatively more obvious corselet difference would elude detection unless the observer was looking for it specifically. This being the case, the question arises as to whether *thynnoides* was present in these waters previous to this capture but was undetected, or whether its recent capture indicates a movement of this fish into the area.

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3. IGY OCEANOGRAPHIC PROGRAM AND THE DEVELOPMENT CONCERNING THE PACIFIC EQUATORIAL UNDERCURRENT[1]

lost of the commitments and plans for oceanogra- : research in the Pacific submitted at preliminary ' meetings were completed. The most intensive erage was in the coastal areas off North America Asia. There were no quasi-synoptic surveys such he 1955 NORPAC[2] and 1956 EQUAPAC[3] surveys. o important strictly IGY projects were the studies obtain data on the age and rate of replacement the deep and bottom waters and studies of the cir- ation and mass transport in the eastern equatorial ific.

he deep circulation studies consisted of direct cur- t measurements from the Russian "R/V Vitiaz" at erous stations around the entire North Pacific deep water sampling in the eastern Pacific from sels of Canada's Pacific Oceanographic Group from naimo, B. C., the University of Washington, and pps Institution of Oceanography. The sampling gram extended from 50°N. to 45°S. latitude.

he studies of the circulation and mass transport the eastern equatorial Pacific consisted of two tiple ship surveys. One was the study of the atorial Countercurrent (Doldrum Expedition) by ipps Institution of Oceanography and the Colombian vy and the other was the study of the Pacific atorial Undercurrent (Cromwell Current) by ipps Institution of Oceanography and the Honolulu logical Laboratory.

he Countercurrent Survey disclosed an average nsport of 60 million cubic meters per second, ich was two to three times that computed from vious observations. The reason for the increase the transport between 200 and 800 meters which revealed by direct measurement of the currents[4]. he Pacific Equatorial Undercurrent (Cromwell Current) survey yielded an estimate of its volume transport and eastern limit. It was found to extend from at least 140°W. to 92°W. longitude and to be completely embedded beneath the surface in the westerly flowing South Equatorial Current. The core of the current was centered on the equator where velocities of 2–3½ knots occurred between 140°W. and 95°W. On 140°W. the current occurred between 30 and 300 meters with the maximum velocities occurring at about 100 meters. It was symmetrical about the equator; thinning and weakening to the north and south so that at 2°N. and 2°S. it was only 30 m. thick and had maximum velocities of only 0.6 knots. The average transport of current on 140°W. was 30 million cubic meters per second or more than that previously given for the Equatorial Countercurrent itself[5].

The importance of the undercurrent studies were that they showed a need for reconsideration of the water balance in the equatorial Pacific and perhaps other areas as well in order to determine the role submerged currents play in the water balance of the oceans and transport of pelagic organisms.

JAMES W. McGARY
U. S. Bureau of Commercial Fisheries
Honolulu, Hawaii

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[1] Published by permission of the Director, U. S. Bureau of Commercial Fisheries.

[2] NORPAC was a multiship survey of the Pacific Ocean north of 20°N. latitude during July–September 1955 by vessels of Canada, Japan, and the United States.

[3] EQUAPAC was a multiship survey of the equatorial Pacific Ocean, 20°N. to 20°S. latitude and west of 130°W. longitude, during August–September 1956 by vessels of France, Japan, and the United States.

[4] J. A. Knauss and R. Pepin, Nature 183: 380 (1959).

[5] J. A. Knauss and J. E. King, Nature 182: 601-602 (1958).

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RECENT OCEANOGRAPHIC CONDITIONS IN THE CENTRAL PACIFIC

PRESENTED BY GARTH I. MURPHY

> (EDITORS' NOTE): *Mr. Murphy in his presentation briefly reviewed material that he distributed to all members of the Symposium. It seemed best that rather than presenting the review by Mr. Murphy that the material distributed should be presented in total. The discussion has been included at the end.*

SURFACE TEMPERATURE ANOMALIES IN THE CENTRAL NORTH PACIFIC, JANUARY 1957-MAY 1958

JAMES W. McGARY

The surface-temperature monitoring program for the Northeastern Pacific utilizing ship's weather report data which was described at the EPOC meetings at Lake Arrowhead last fall was started in October 1957. Since that time we have prepared a complete series for the middle ten days of each month from January 1957 through May 1958. The final form consists of a series of four plots for each month, the actual temperature contours and the anomalies from the 30-year mean (H. O. 225), the tabulation of all temperature data available for the Pacific east of 180° and between 20°N and 30°S., and since January 1958 the anomaly of 1958 from 1957. The procedure used in constructing the temperature charts of the Northeastern Pacific was basically the same as that used by Dr. Takenouti's group at JMA for the Northwestern Pacific and which was verified by a check against research vessel temperature data by Franceschini of Texas A & M. This procedure is quite simple, the temperatures are decoded, averaged by one-degree square, and contoured assuming they represent the average for the center of the squares. The anomaly charts are drawn by overlaying the monthly and normal charts on a light table.

The anomaly charts appear to have the most promise for tracing major changes in temperature in spite of the fact that they contain many small cells which have no month-to-month continuity. Actually many of the small changes in the anomalies from the 30-year mean are the result of the difference in techniques used in their construction. The 30-year mean charts were interpolated from H. O. 225 and hence represent data that has had a maximum of smoothing while the monthly charts are drawn strictly on the distribution of temperature indicated by averages for the one-degree squares after the obviously bad values have been culled out.

Most of the large features in the 30-year anomaly charts persist from month to month but their change in size, shape, and geographical position is more amoeboid in nature than can be accounted for by advection by the normal ocean currents. This leads to speculation as to the need for the computation of new mean-temperature charts. Examination of the major features of the area to the north and northeast of the Hawaiian Island chain will illustrate the manner in which these changes occur.

In January 1957 (Fig. 14) except for a few small cells the major portion of the area west of 145°W. longitude was 2°F. or greater, warmer than normal. By February (Fig. 15) in the area north of 35°N. the warming had persisted and the anomaly had increased in many places while to the south of 35°N. the positive anomaly had decreased in intensity. For March (Fig. 16) there were only minor changes in the distribution of positive and negative anomalies in the mid-ocean area but the amount of the positive anomaly had decreased. In April (Fig. 17) except for a few areas along 45°N., the return towards normal conditions had continued although most of the area was still slightly warmer than normal.

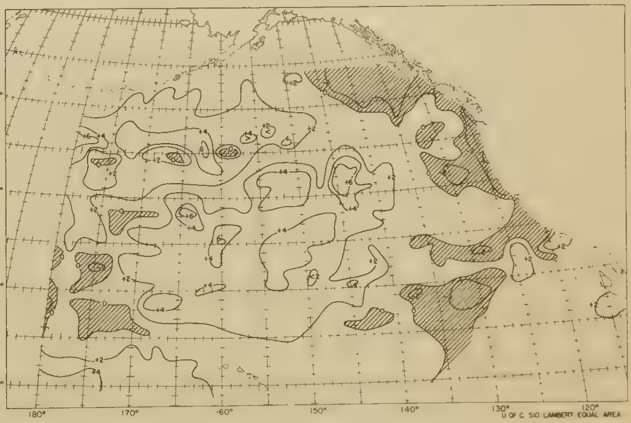


FIGURE 14. January 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.

In May 1957 (Fig. 18) the dominant anomaly of the area was still 0 to 2°F. warmer than normal but there had been a slight increase in the areas of cold anomaly. This increase became pronounced in June (Fig. 19) and a tongue of cold water extended east between 35° and 60°N. latitude from 180° to 135°W. but outside this area the areas having positive anomalies of +2°F. or greater increased. This was the basic distribution throughout the summer with the tongue of cold water in the west or northwest merely changing shape and retreating or expanding (Figs. 20, 21).

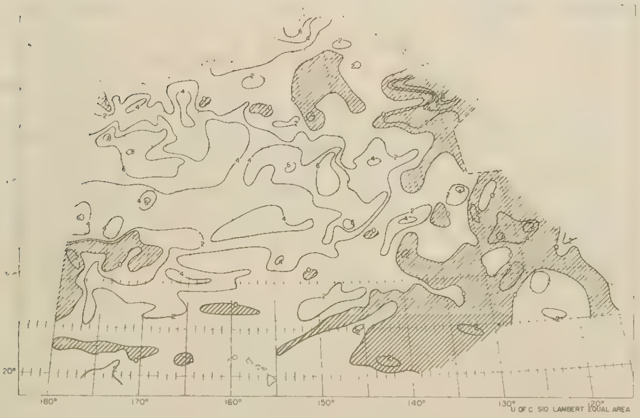


FIGURE 15. February 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.

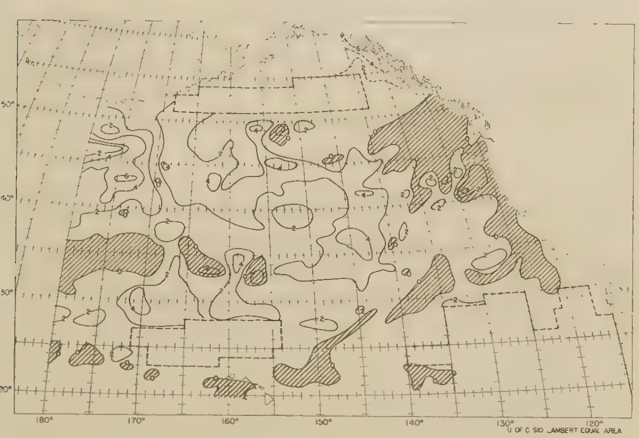


FIGURE 16. March 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.

In the fall and early winter (Figs. 22-25) basically the same conditions existed; cold anomalies appear in the extreme west and positive anomalies reaching a maximum of greater than 6°F. dominate the eastern part of the charts.

In January 1958 (Fig. 26) the warm 0 to +2°F. anomaly was still dominant but there was really no distinct pattern of cold (<0°F.) and warm (>+2°F.) areas.

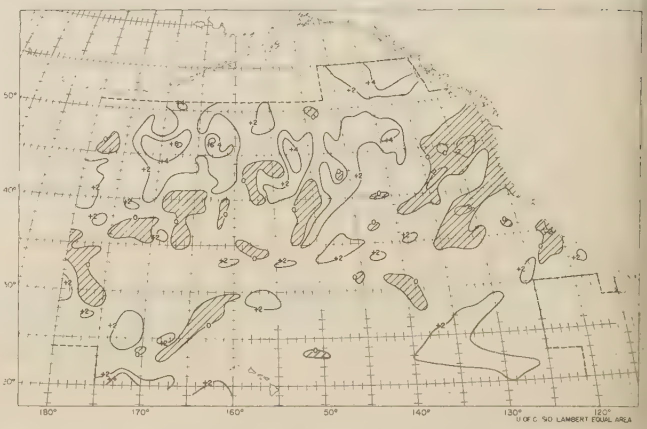


FIGURE 17. April 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.

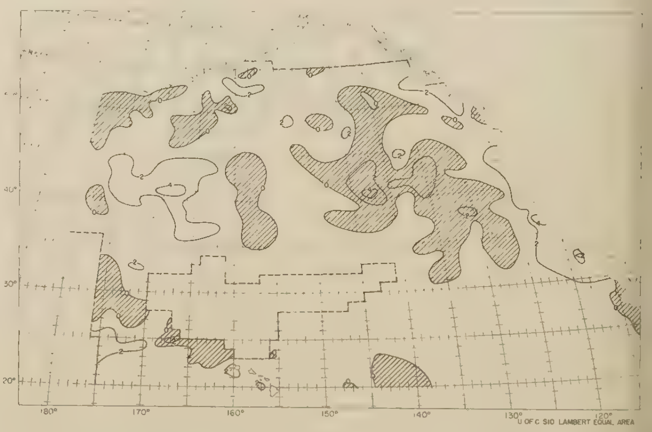
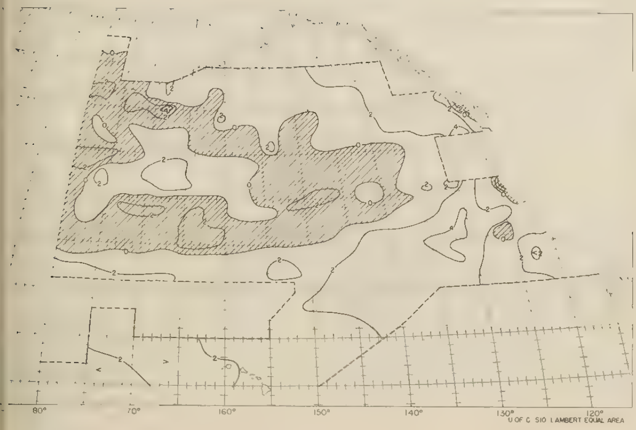


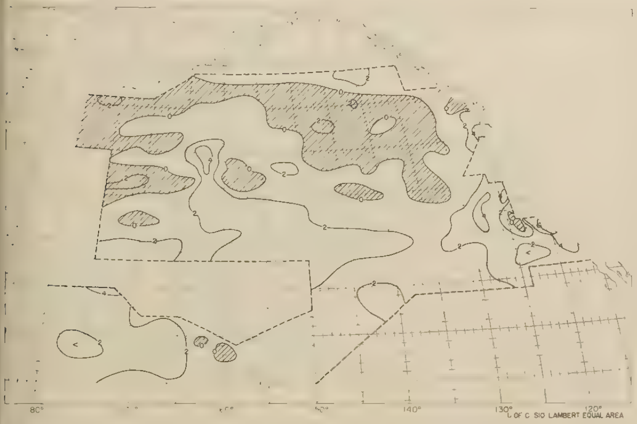
FIGURE 18. May 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.

In February 1958 (Fig. 27) the areas of cold anomaly began a distinct increase in size and the percentage of the areas having surface temperatures below normal continued to increase through May (Figs. 28-30). However, there appeared to be no definite pattern to their increase.

The yearly (1958-1957) charts (Figs. 31-35) appear to have the most persistent features and in most areas exhibit month-to-month changes that would be expected from the accepted circulation pattern in the Northeastern Pacific. For example the January-April 1958 charts show a steady encroachment of the area of negative anomaly from mid-ocean towards the coast. It reached the coast in March at 38° to 40°N. where the monthly temperature charts indicate the divergence in the currents occur and in April it continued to spread north and south.


80°
70°
160°
150°
140°
130°
120°
U OF C SIO LAMBERT EQUAL AREA

GURE 19. June 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.


80°
140°
130°
120°
U OF C SIO LAMBERT EQUAL AREA

IGURE 20. July 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.

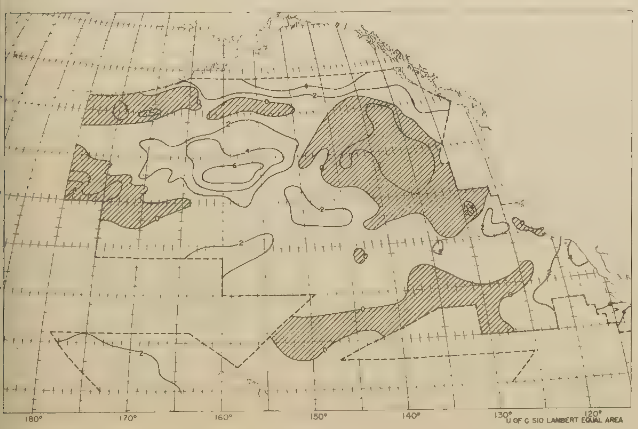

180°
170°
160°
150°
140°
130°
120°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 21. August 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.

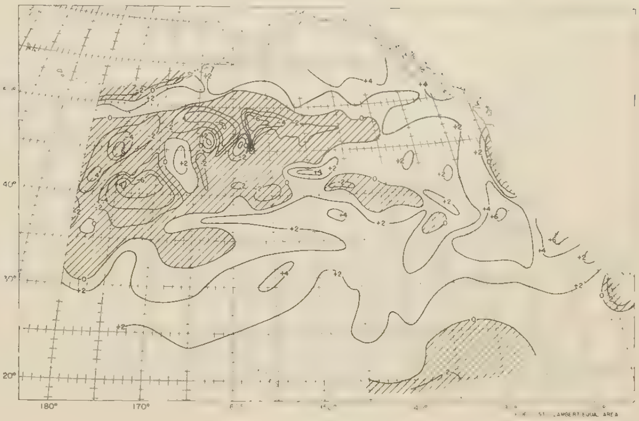
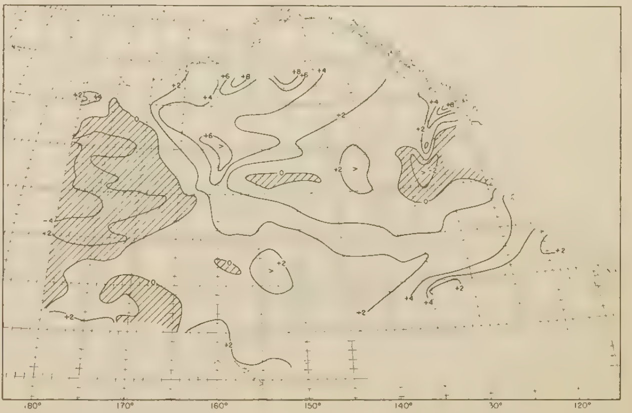

40°
30°
20°
180°
170°
+2
+4
LAMBERT EQUAL AREA

FIGURE 22. Sept. 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.


50°
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20°
180°
170°
160°
150°
140°
30°
120°
+2
+4
+6
+8

FIGURE 23. October 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.

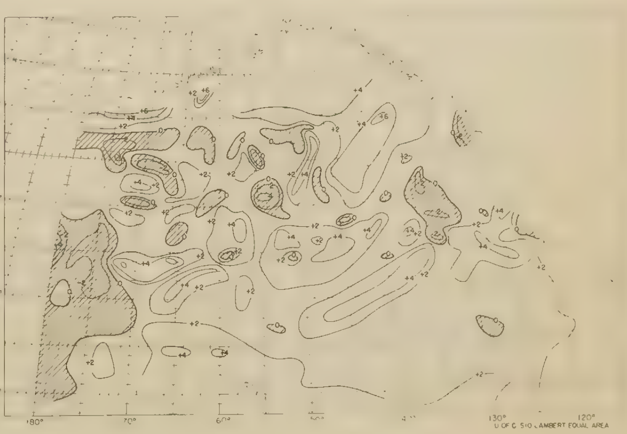
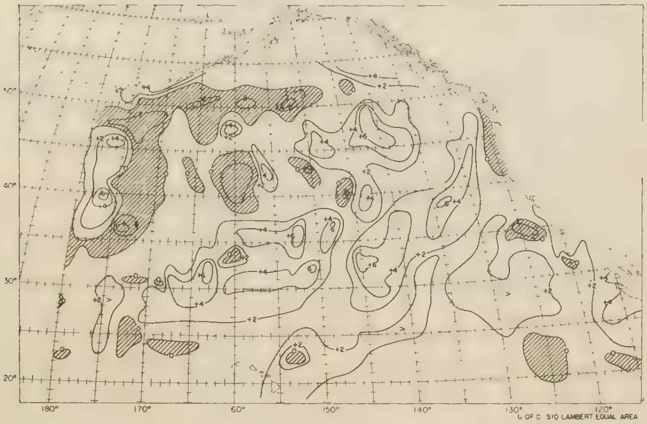

40°
30°
20°
180°
70°
60°
130°
120°
U OF C SIO LAMBERT EQUAL AREA
+2
+4
+6

FIGURE 24. Nov. 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.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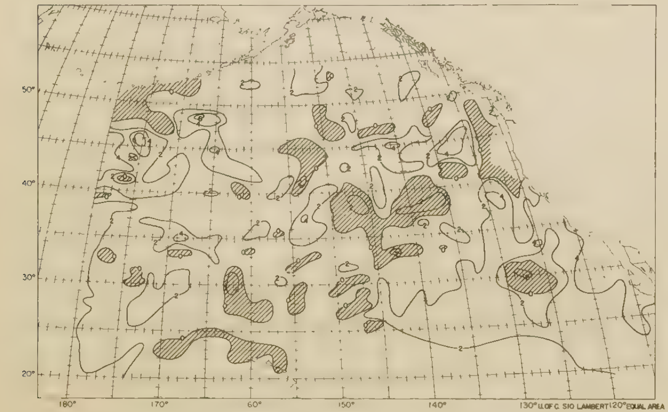
130°
120°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 25. Dec. 11-20, 1957. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O.. 225. Hatched areas colder than average.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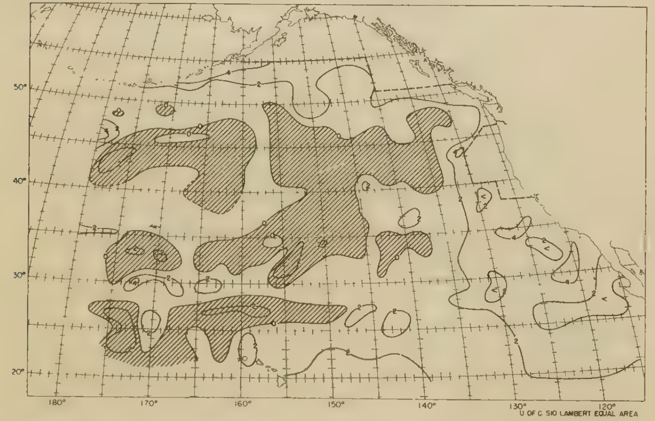
150°
140°
130° U OF C SIO LAMBERT 120° EQUAL AREA

FIGURE 26. Jan. 11-20, 1958. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.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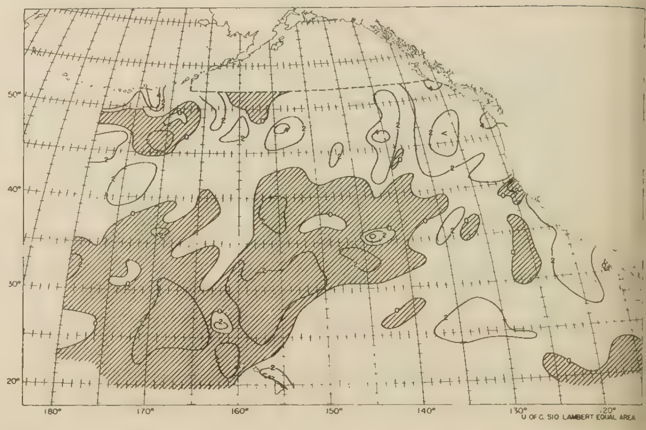
120°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 27. Feb. 11-20, 1958. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.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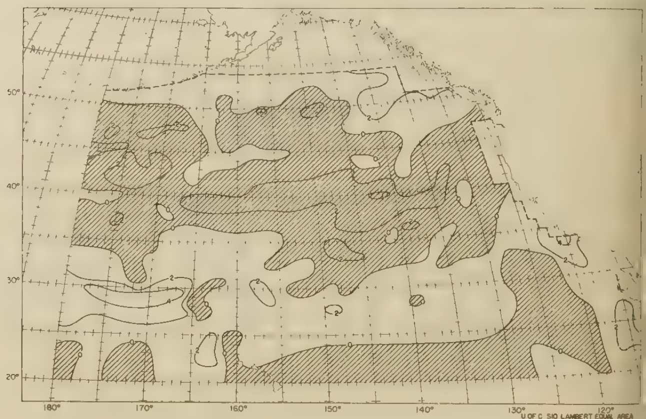
140°
130°
120°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 28. Mar. 11-20, 1958. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.


50°
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160°
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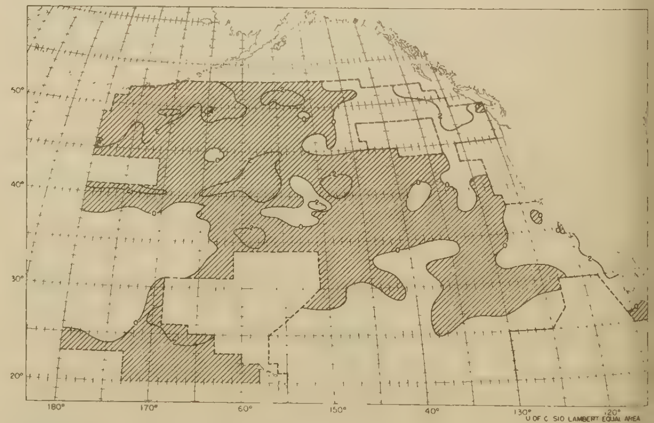
130°
120°
U OF C SIO LAMBERT AREA

FIGURE 29. Apr. 11-20, 1958. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.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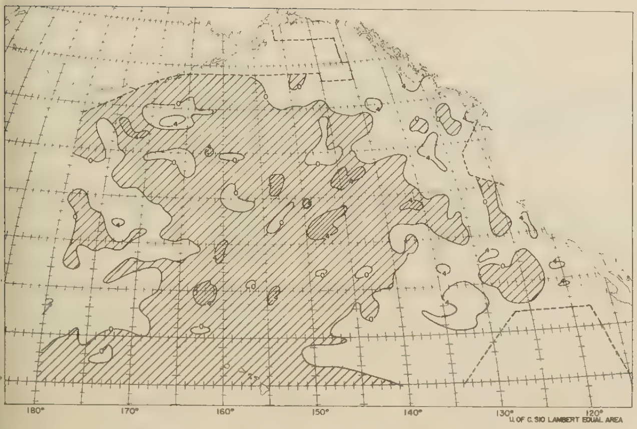
U OF C SIO LAMBERT EQUAL AREA

FIGURE 30. May 11-20, 1958. Anomaly of sea surface temperature (°F) from 30-year mean charts of H.O. 225. Hatched areas colder than average.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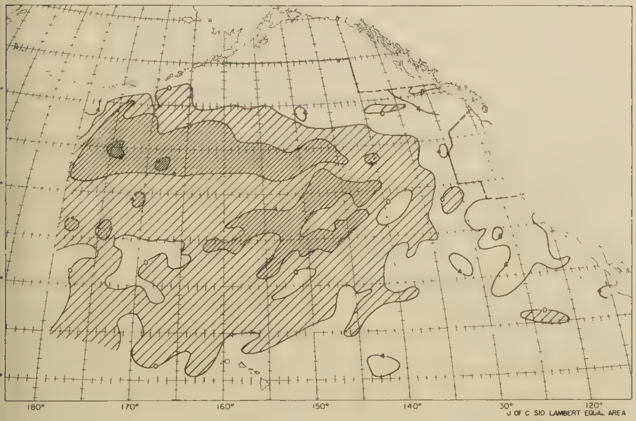
U. OF C. SIO LAMBERT EQUAL AREA

GURE 31. Jan. 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 than 1957.


180°
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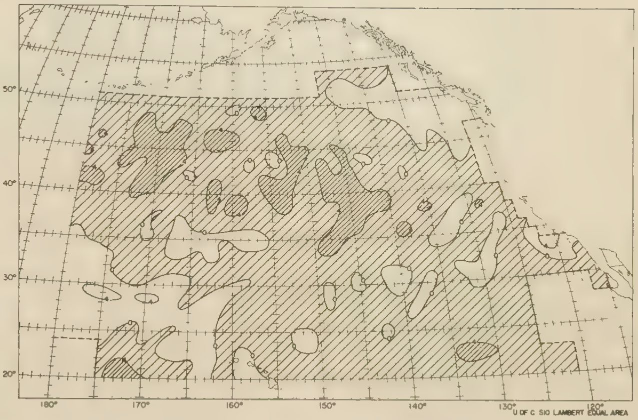
U OF C SIO LAMBERT EQUAL AREA

IGURE 32. Feb. 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 and 1957.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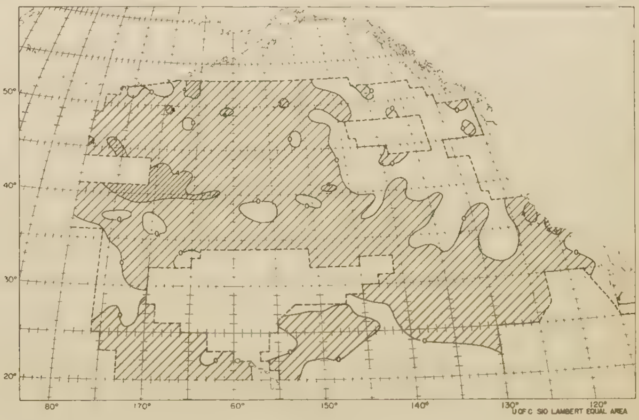
130°
120°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 34. April 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 than 1957.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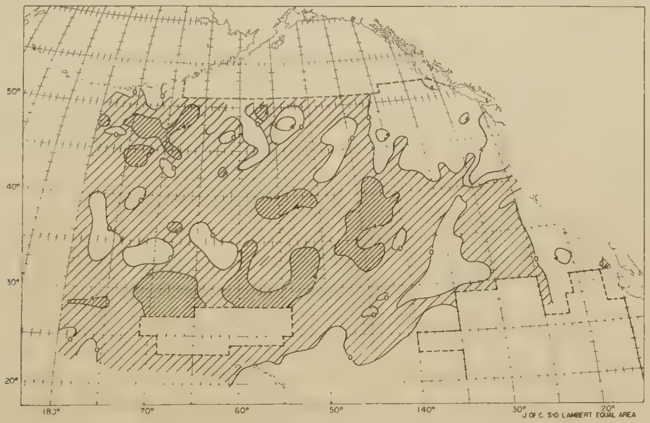
U OF C SIO LAMBERT EQUAL AREA

FIGURE 35. May 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 than 1957.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50°
140°
30°
20°
U OF C SIO LAMBERT EQUAL AREA

FIGURE 33. March 11-20; 1958 minus 1957. Surface temperature change. Hatching indicates areas colder in 1958 than 1957.

SUMMARY, 1955-57 OCEAN TEMPERATURES, CENTRAL EQUATORIAL PACIFIC

THOMAS S. AUSTIN

PACIFIC OCEANIC FISHERY INVESTIGATIONS

MONTEREY AND MARIPOSA DATA

Late in 1956, POFI made arrangements whereby two passenger liners, the SS *Mariposa* and the SS *Monterey*, were to collect surface temperature data and salinity samples once each watch (four-hour intervals) during their passage, Honolulu to Tahiti and/or Pago Pago and return. As a result of these arrangements, at least one surface temperature and one salinity section, along the courses traversed by these vessels, are available for each month, November 1956 to present.

In figure 36, the temperature data have been expressed as anomalies from the mean; positive anomalies have been shaded. Along the top of the panel for each month, the inclusive dates for the section, th vessel(s) (MO-*Monterey*, MA-*Mariposa*), and th ports of call (H-Hawaii, T-Tahiti, and PP-Pago Pago) are given. When both vessels made the run durin any one month, their observations have been average and a single curve drawn. Mean temperatures, t which the observed temperatures were algebraicall compared, were taken from the Monthly Meteorological Charts of the Western Pacific Ocean.[1]

When departing Honolulu (right end of each panel) (Fig. 36) and proceeding south, the vessels crossed th

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[1] British Air Ministry, Monthly Meteorological Charts of th Western Pacific, MO-484, 120 p.

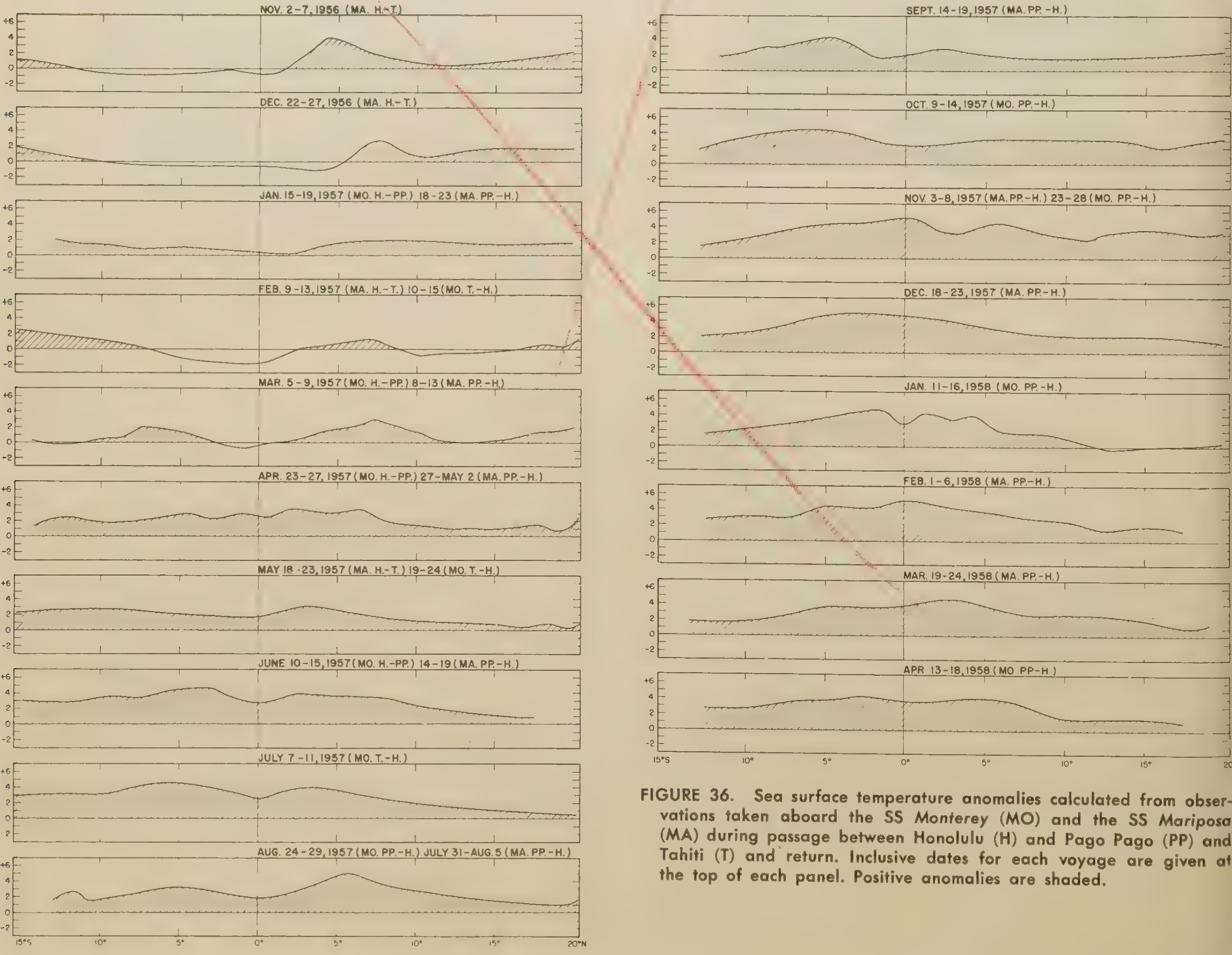


FIGURE 36. Sea surface temperature anomalies calculated from observations taken aboard the SS *Monterey* (MO) and the SS *Mariposa* (MA) during passage between Honolulu (H) and Pago Pago (PP) and Tahiti (T) and return. Inclusive dates for each voyage are given at the top of each panel. Positive anomalies are shaded.

DISPLAY COPY

Biological and Oceanographic Observations in the Central North Pacific July — September 1958

SPECIAL SCIENTIFIC REPORT — FISHERIES No. 358

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Bureau of Commercial Fisheries
Honolulu Biological Laboratory
P. O. Box 3830, Honolulu, Hawaii

Recently, it was discovered that the depths of reversal of the Nansen bottles, as calculated at the Honolulu Biological Laboratory from temperature differences of unprotected and protected reversing thermometers, are in error. These depths, which are in excess of the correct depth, may be reduced to the proper value by the use of a correction factor, as described below.

At the time the data processing system in use at this laboratory was being established, a table of the factor $1/(Q \times \rho_m)$ was prepared for use in computing the depths of reversal from the readings of unprotected thermometers; Q represents the pressure-constant of an unprotected thermometer, and ρ_m represents the mean density of the water column above the depth of thermometer reversal, which was taken to be 1.0303 in all cases. An error occurred in the calculation such that, instead of $1/(Q \times \rho_m)$, the table consisted of values of $(1/Q) \times \rho_m$. This error is present in all of the depth data which have been published by this laboratory under its previous name, Pacific Oceanic Fishery Investigations, and under its present name, Honolulu Biological Laboratory, up to and including 1960. Therefore, in making use of the data published by this laboratory before 1961, all depths should be corrected by dividing each by $(\rho_m)^2$, which is equal to 1.0615. Multiplication of all the published depths by 0.942 will give the proper value for the depth of each observation.

Thomas S. Austin
Thomas S. Austin
Assistant Laboratory Director

United States Department of the Interior, Fred A. Seaton, Secretary
Fish and Wildlife Service, Arnie J. Suomela, Commissioner
Bureau of Commercial Fisheries, Donald L. McKernan, Director

BIOLOGICAL AND OCEANOGRAPHIC OBSERVATIONS IN THE CENTRAL NORTH PACIFIC JULY-SEPTEMBER 1958

By

James W. McGary, Oceanographer

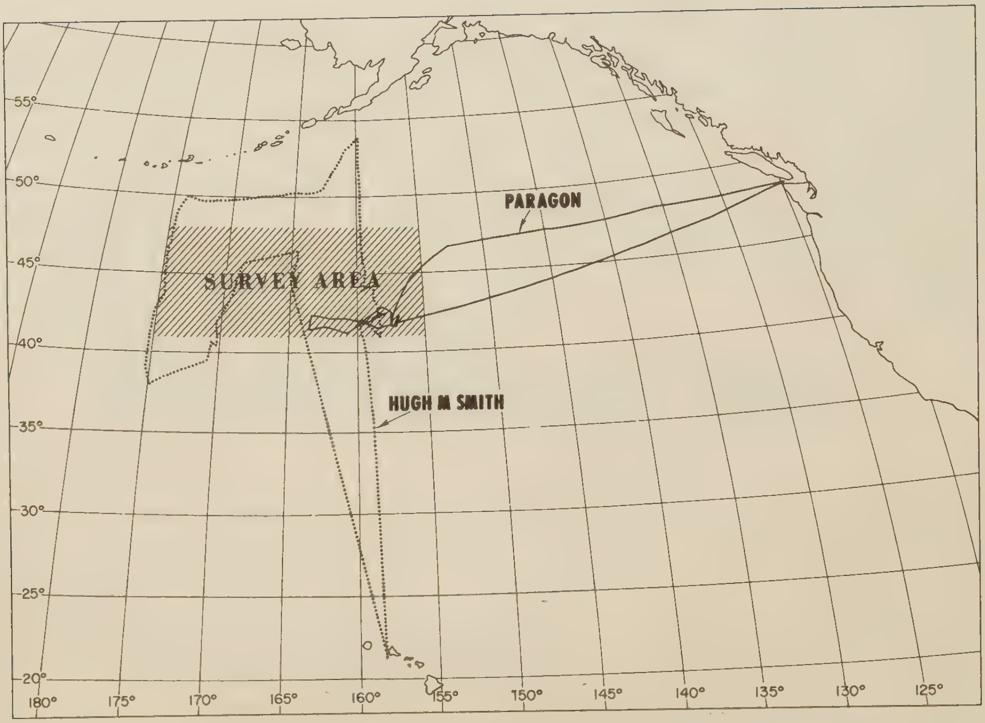
and

Joseph J. Graham
Fishery Research Biologist
Honolulu Biological Laboratory

March 3, 1849

United States Fish and Wildlife Service
Special Scientific Report: Fisheries No. 358

Washington, D. C.
December 1960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PARAGON
SURVEY AREA
HUGH M SMITH

Frontispiece: Chart of the Northeastern Pacific showing tracks of *Hugh M. Smith* cruise 46 (broken line) and M/V *Paragon* (solid line).

ABSTRACT

This report contains the biological (including fishing) and oceanographic data collected in the central North Pacific during the July-September 1958 period from the U. S. Bureau of Commercial Fisheries research vessel *Hugh M. Smith* and the M/V *Paragon*. The latter made a commercial-scale gill-net survey for albacore under a contract with the Bureau. Scientists and crew aboard the former collected oceanographic, biological, and fishing data to permit a comparison of conditions in 1958 with those of previous years. The major effort of both vessels was in the area between 155° and 175°W. longitude and from 41° to 48°N. latitude.

CONTENTS

Page

Introduction. 1

Field procedures 2

  Biological studies 2

    Exploratory fishing 2

    Tagging 5

    Food studies 5

    Forage organisms 5

    Observation of bird flocks, fish schools, and aquatic mammals 5

    Plankton volumes. 5

  Oceanographic studies 5

    Water sampling 5

    Water temperature 6

    Meteorological observations 6

    Subsurface illumination observations 6

Laboratory methods and techniques. 6

Future publication. 11

Personnel. 11

Records. 11

Literature cited 11

Tabulated data 13

Appendix A - carbon and phytoplankton data 97

ILLUSTRATIONS

FIGURE | Page

Frontispiece: Chart of the Northeastern Pacific showing tracks of Hugh M. Smith cruise 46 (broken line) and M/V Paragon (solid line).

1. Track chart, Hugh M. Smith cruise 46 2
2. Schematic view of longline gear, Hugh M. Smith cruise 46 3
3. Positions of gill-net sets, M/V Paragon. 4

4-13. Temperature-depth sections (A-J), Hugh M. Smith cruise 46 7

TABLES

TABLE

1. Summary of the types of observations (except C_{14}) made at Hugh M. Smith cruise 46 stations. 13
2. List of common and scientific names and abbreviations used in HBL data for fish encountered during cruise 46 of the Hugh M. Smith and that of the M/V Paragon . . 16
3. Summary of gill-net catches, Hugh M. Smith cruise 46 17
4. Summary of gill-net catches, M/V Paragon 18
5. Summary of surface trolling, Hugh M. Smith, cruise 46 19
6. Summary of surface trolling catches, M/V Paragon. 20
7. Summary of longline catches, Hugh M. Smith cruise 46. 21
8. Length frequency distribution, by stations, of albacore caught by the gill net, Hugh M. Smith cruise 46 22
9. Length frequency distribution, by stations, of albacore caught by the gill net, M/V Paragon. 23
10. Summary of night light observations on the abundance of saury and squid, Hugh M. Smith cruise 46 24
11. Record of daily sightings of bird flocks, scattered birds, fish schools, and aquatic mammals, Hugh M. Smith cruise 46 25
12. Zooplankton station data and volumes, Hugh M. Smith cruise 46 26
13. Station curves and observed oceanographic data, Hugh M. Smith cruise 46 28
14. Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46. 81
15. Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), M/V Paragon 90

TABLES (cont'd)

TABLE

Page

16. Log of ship's weather observations, Hugh M. Smith cruise 46 (U. S. W. B. Form 1210F in International Ship Weather Code). 91
17. Summary of observations made at submarine photometer stations, Hugh M. Smith cruise 46. 96

BIOLOGICAL AND OCEANOGRAPHIC OBSERVATIONS IN THE CENTRAL NORTH PACIFIC JULY-SEPTEMBER 1958

By

James W. McGary, Oceanographer

and

Joseph J. Graham
Fishery Research Biologist
Honolulu Biological Laboratory
Honolulu, Hawaii

One of the primary objectives of the Honolulu Biological Laboratory's studies of the albacore, Thunnus germo (Lacépède)[1/], has been to determine whether there are albacore in commercial quantities in the central Pacific north of the Hawaiian Islands. A series of exploratory fishing cruises was made by Honolulu Biological Laboratory (subsequently referred to as "HBL") vessels between January 1954 and December 1956. The pattern of the cruises was such that there was geographic coverage of the area during all seasons of the year (Graham 1957, Shomura and Otsu 1956, and Callaway 1957). The results indicated that the only place where albacore concentrations of commercial value occurred was within the area between 155°W. and 175°E. longitude from 42° to 48°N. latitude. Here, where previous cruises using longline and trolling gear had been relatively unsuccessful, promising gill-net catches of albacore were made from vessels of the Bureau of Commercial Fisheries' Seattle Biological Laboratory during July-August 1955 salmon surveys. The contrast between gillnetting and other types of fishing was further accentuated by the fact that in the same area and during the same period only a few albacore were caught by trolling from an HBL vessel. The John R. Manning (HBL) returned to the area during the summer of 1956 and obtained similar results: good gill-net and poor troll catches.

These results suggested that the logical next step was a commercial-scale gill-net test with supporting environmental studies to permit a comparison of the catches and conditions with those of previous years. Consequently, a commercial vessel was chartered to make a gill-net survey of the area during the summer of 1958, and a Bureau vessel was assigned to collect the supporting scientific information.

The research vessel Hugh M. Smith was assigned to the combination oceanographic-biological survey, which included exploratory fishing to define the northern and southern limits of albacore distribution and to test the relative effectiveness of gill-nets, longlines, and trolling gear. HBL scientists aboard the Smith were also to provide the contract vessel with any data that might contribute to the success of the commercial fishing.

The Smith departed from Honolulu on July 21, 1958, and arrived in the survey area on July 28, 1958. On September 4, 1958, the survey was ended and the Smith returned to Honolulu on September 9.

The M/V Paragon was chartered from Northwest Fisheries, Inc., of Seattle, Washington to make the commercial-scale trial of gill-netting. The Paragon is a halibut schooner having an overall length of 90 feet, a beam of 19 feet 5 inches, a draft of 9 feet (empty), a maximum speed of 11.0 knots, and a cruising speed of 10.5 knots. The Paragon participated in exploratory salmon gill-net fishing in the Bering Sea-Aleutian Islands area during the summers of 1955, 1956, and 1957. In fact, it was one of the vessels, while under charter to the Seattle Biological Laboratory, from which good gill-net catches of albacore were made during the summer of 1955.

The limits of the fishing area given in the Paragon's contract included all of the area where promising catches had been made during 1955 and 1956 that were within the range of fishing vessels that might operate out of the Aleutian ports. The western limit was 175°W. longitude and the eastern limit 155°W. The northern and southern limits were 48°N. and 41°N. (see frontispiece). The selection of the actual positions of the gill-net sets within the area was left to the discretion of the Master. Trolling while underway was required during daylight hours both within the contract fishing area and

---

[1/] Also known as Germo alalunga (Bonnaterre), Thunnus alalunga (Gmelin), and Germo germo (Lacépède).

en route to and from the area. The Master of the Paragon was directed to complete the required fishing between July 20 and September 10, 1958. The required fishing consisted of either (1) sufficient sets of 7-1/2- to 8-1/2-inch (stretched measure) mesh gear to total 1,200 shackles or (2) an albacore catch of 60 tons.

The Paragon departed from Seattle, Washington on July 16, 1958, and arrived in the survey area on July 26, 1958. The 1,200-shackle fishing requirement was completed on August 30, 1958, and the vessel returned to Seattle on September 5, 1958. The track is shown in the frontispiece.

FIELD PROCEDURES

Biological Studies

Exploratory fishing.--Nineteen gill-net sets (tables 1 and 3 and fig. 1) were made from the Hugh M. Smith during 28 nights of operation in the band of 53°-66°F. surface temperatures which past cruises had shown to approximate the latitudinal limits of the mid-ocean albacore. The remaining nine nights were lost because of unsuitable weather at setting time. On only one of these nights did the weather moderate enough so that it would have been possible to retrieve the net at dawn without excessive damage. At two of the stations the wind and sea increased during the night. At station 61 the seas rolled or tangled the net to such a degree that only 1/3 of the net was fishing properly when it was retrieved. At station 68 the net was retrieved in winds having gusts up to 26 knots and the net was so badly damaged that 2 days were required to repair it. Thus, the number of nights that were suitable for gill netting was 18 out of 28 or about 65 percent.

Each of the sets from the Smith consisted of 10 shackles of 4-1/2-inch to 7-1/2-inch (stretched measure) mesh gill net. The construction details of this gear have been described by Graham and Mann (1959). At the first six stations (those between stations 22 and 40) each set consisted of one 4-1/2-, one 5-1/2-, four 6-1/2-, and four 7-1/2-inch mesh shackles. With the completion of these stations the usable shackles of 7-1/2-inch mesh gear had been reduced to three, so the number of 6-1/2-inch mesh shackles was increased to five.

Albacore were taken in seven of the gill-net sets, with a total catch of 97 fish. The largest catches were 49 albacore at station 67 (42°7'N., 175°08'W.) and 26 at station 63 (43°29'N., 174°48'W.) (table 3 and fig. 1). Second sets at these stations produced 7 and 3 albacore, respectively. Catches at the other three stations were 3, 4, and 5 albacore. Catches of species other than albacore tuna are also listed in table 3. Five lines were trolled from the Smith during daylight hours, at a speed of 6.5 knots, when in areas having surface temperatures between 52° and 72°F. Two lines were trolled at standard speed (9 knots) during daylight hours in all other areas. Within the 52°-72°F. surface temperature range it was occasionally necessary to reduce the number of lines to avoid tangling during rough weather or to increase to standard speed after longline stations or between north-south transects in order to obtain the desired gill-net station spacing. The trolling results are summarized in table 5.

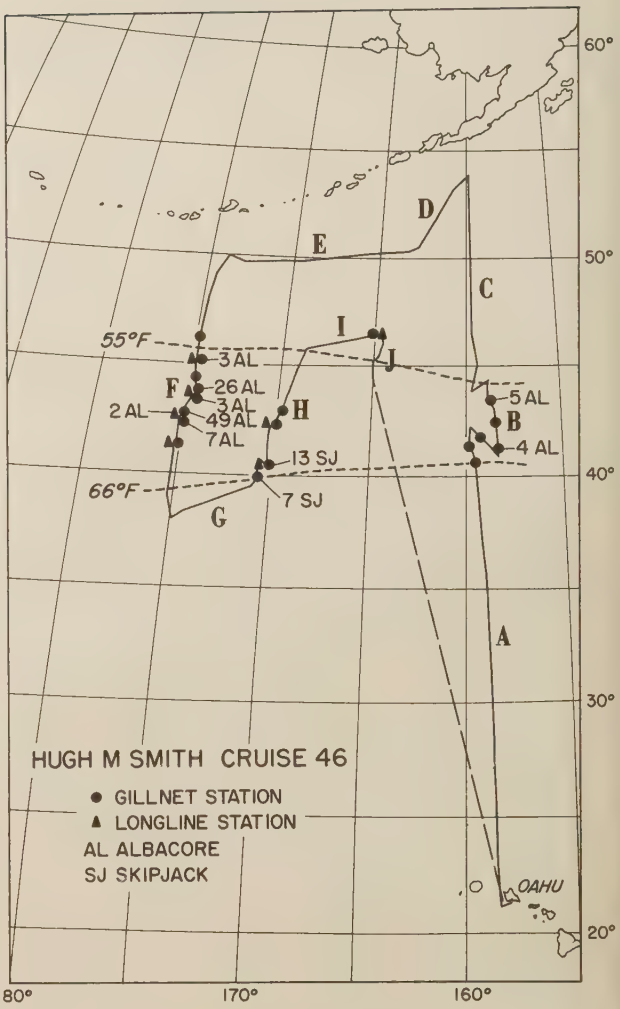


Figure 1.--Track chart, Hugh M. Smith cruise 46, July 21 to September 9, 1959, showing gill-net and longline stations. Letters and solid lines designate the location of temperature sections shown in figures 4 to 13.

Trolling patrols were made along the longline to compare the catch of albacore by the two types of gear. Since fog frequently made it inadvisable to venture more than a quarter of a mile from the longline, the patrols were limited to 3 hours to avoid the possibility of unduly interfering with the fishing of the shallow hooks of the longline gear.

Thirteen albacore were taken during the 212 hours of trolling in water having surface temperatures between 52° to 72°F. There were two catches of two albacore each. The others were taken singly, even though a thorough sweep of the area was made after each strike.

Seven sets of shallow longline gear were made from the Smith at the positions indicated in figure 1 and in tables 1 and 7. All longline sets either preceded or followed a gill-net set. Each consisted of 20 baskets of 12-hook gear with a buoy on the mainline at each dropper, so that the fishing depth depended solely on the length of the dropper. Each basket had three 12-, three 24-, three 48-, and three 96-foot droppers, arranged as shown in figure 2. The gear was set at daylight and allowed to fish a minimum of 6 hours.

Only two albacore were taken on the longline. Both were taken at station 67 (42°48'N., 175°03'W.), one on a 24- and the other on a 48-foot dropper. Both were taken within the mixed layer; the thermocline depth was 50 feet. The longline catches are summarized in table 7.

No difficulties were encountered in setting the longline, but it was difficult to retrieve. The shallowness of the line and the varying depth of the droppers made it very liable to distortion by differences in local ocean currents and by the struggles of hooked fishes. Large curves usually formed in the mainline, and at several of the stations one or more of the end baskets doubled back on the mainline. There was considerably more tangling of the droppers on the mainline than occurs with conventional longline gear. An unsuccessful attempt to overcome this difficulty by using smaller floats, which would just keep the line afloat, was made at station 90. Hooked sharks sounded with the line, and the resulting mixture of shallow and deep sections of the mainline and added horizontal distortion only increased the difficulty of retrieving the line.

Table 8 gives the length frequency distributions of the albacore caught by gill net from the Smith. The lengths of albacore taken on troll lines and longline are given in tables 5 and 7, respectively.

The crew of the Paragon completed the 1,200-shackle contract requirement by fishing 30 sets of 40 shackles each. The first set was made on July 26, 1958, and the final set on August 30, 1958. The positions of the sets are shown in figure 3. The 30 sets were completed in only 35 nights largely because it was possible to work from the vessel in winds up to approximately 25 knots. Of the five nights not fished, only three were lost because of bad weather at setting time. The other two were lost because the seas which resulted from the 40-50 knot winds that developed during set No. 21, on the night of August 17, 1958, rolled and tangled the

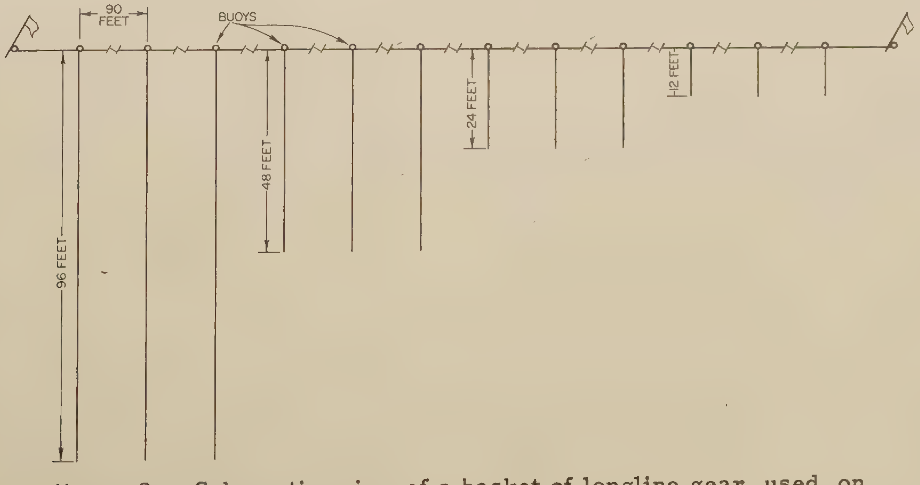


Figure 2.--Schematic view of a basket of longline gear used on Hugh M. Smith cruise 46.

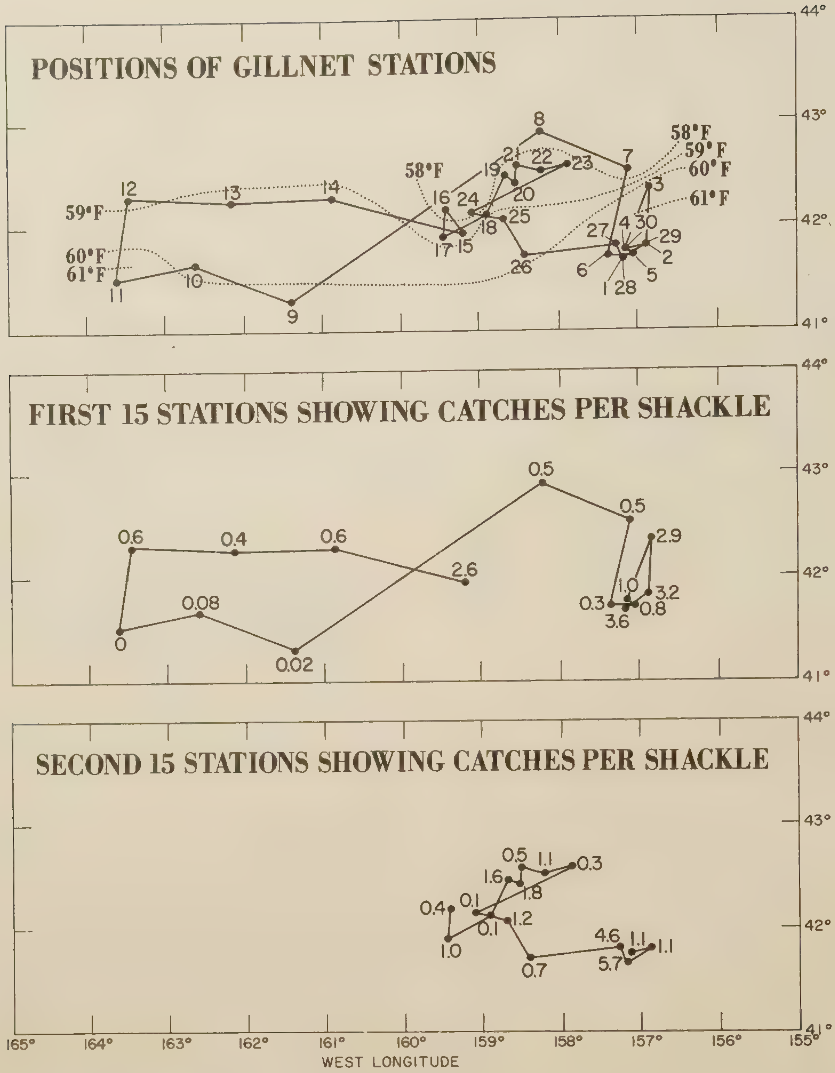

POSITIONS OF GILLNET STATIONS
FIRST 15 STATIONS SHOWING CATCHES PER SHACKLE
SECOND 15 STATIONS SHOWING CATCHES PER SHACKLE
58°F
59°F
60°F
61°F
44°
43°
42°
41°
165°
164°
163°
162°
161°
160°
159°
158°
157°
156°
155°
WEST LONGITUDE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
0.6
0.4
0.6
2.6
0.5
0.5
2.9
0.08
0
0.02
1.0
0.3
3.6
0.8
3.2
0.5
1.1
0.3
1.6
1.8
0.4
0.1
0.1
1.2
1.0
0.7
4.6
1.1
1.1
5.7

Figure 3.--Positions of gill-net sets made from the M/V Paragon (upper panel) and catch rates per shackle (middle and lower panels), July-August 1958.

net so badly that 3 days were required to repair it. Thus, allowing for the night when high winds developed during the set, 31 out of 35, or about 89 percent, of the nights were suitable for fishing with gill net from the Paragon.

The dimensions of the shackles specified in the contract were a minimum of 50 fathoms (300 feet) in length, 5 fathoms (30 feet) in depth, and 7-1/2 inches to 8-1/2 inches stretched mesh. The actual selection of the size or sizes of mesh within that range was left to the discretion of the contractor. As a guide in selecting the size, he was provided with a summary of the 1955 and 1956 results, as well as those from earlier gill-net experiments of the North Pacific Fisheries Exploration and Gear Research (Powell et al. 1952). The sizes selected were 13 shackles of 7-1/2-, 13 of 8-, and 14 of 8-1/2-inch mesh.

The gill-net catches included 1,617 albacore, representing an average catch of 0.6 fish per shackle with extremes for individual sets of 0 and 5.7 (fig. 2 and table 4). Other species taken in the net are also included in the tabulated data. Their scientific names are given in table 2.

Loss of albacore while hauling the net was small (17 fish or 1.05 percent of the catch). Sharks destroyed 94 fish or 5.8 percent. Some of the destruction occurred during retrieving.

The sizes of albacore taken by gill net from the Paragon (table 9) were determined by measuring the fork length of a 30-40 fish sample from each catch.

Six lines were trolled from the Paragon while enroute to the survey area and eight within the area. The troll catch was 233 albacore. Of these, 212 were taken in the gill-net fishing area, representing a catch rate of 1.1 fish per hour trolled. The trolling results and lengths of troll-caught albacore are given in table 6.

The total albacore catch landed at Seattle, Washington, from the Paragon was 27,053 pounds. Of this, the marketable fish amounted to 24,000 pounds.

Tagging.--Three albacore were tagged on the Smith with Honolulu Biological Laboratory dart tags (Yamashita and Waldron 1958) (table 5).

Food studies.--Albacore stomachs from 2 days' catch of the Smith's gill nets and from all the albacore from the longline and troll catches, except for the three which were tagged, were preserved for laboratory analysis.

Forage organisms.--Observations of the abundance of forage organisms, using a 300-watt light submerged to a depth of 1 meter, were made on the Smith. At least one estimate was made of the relative number and size of the saury and squid under the ship's cargo lights while drifting at each oceanographic and gill-net station. A summary of the data is given in table 10.

Three 20-minute tows were made in the survey area from the Smith using the Isaacs-Kidd midwater trawl (King et al. 1957). The positions are given in table 1. They were made at night with the trawl submerged to approximately the middle of the mixed layer. The catches were negligible, consisting only of a few euphausiids, calanoid copepods, and myctophids.

Although no formal record was kept, night light observations were made from the Paragon with a 100-watt light placed 1 foot outboard and 10 feet above the water. During the gill-net sets the light was turned on for a 30-60 minute period after it had become completely dark. The general absence of organisms under the light was striking with one exception; at station 18 (table 4) a large (1,000-fish) school of saury, Cololabis sp., was observed. The results of daylight observations were similar in that only a few small organisms such as saury, Vellela sp., and pelagic barnacles were sighted.

Observations of bird flocks, fish schools, and aquatic mammals.--The wheel-watch of the Smith made observations of fish schools, birds, and aquatic mammals (table 11). Only one albacore school was sighted during the cruise. It was sighted at 45°08'N., 174°47'W. while the vessel was patrolling a longline set, but no albacore were taken on either the trolling lines or the longline.

Plankton volumes.--Twenty-nine 0-14-m. oblique, two 0-60-m. oblique, and 25 surface plankton tows were made with a 1-meter net of 656 Nitex netting (aperture openings 0.65 mm.) described by King and Demond (1953). An additional seven surface hauls were made with a 45-cm. net of similar construction with 303 Nitex netting (aperture opening 0.30 mm.). Five of these seven tows were made across a temperature front centered at 41°30'N., 175°07'W. The positions and types of tows are listed in table 1 and the plankton volumes are given in table 12.

Measurements of the rate of photosynthetic carbon fixation by use of the radioactive carbon method developed by Steemann Nielsen (1952) and modified by Doty (King et al. 1957), were made aboard the Smith by a staff member of the University of Hawaii. Surface and 20-meter samples were collected at 0800 and 2000 daily throughout the cruise, except for the September 4-9 period, when the 20-meter sample was omitted to avoid loss of time. Three 24-hour series were also run, one just north of the Hawaiian Islands, one at the extreme northern latitude reached on the cruise, and one at the southern extremity of the 175°W. longitude transect. At five of the longline stations, 6-hour in situ experiments were run with bottles at 100-percent, 75-percent, 25-percent, 10-percent, 5-percent, and 1-percent levels of the surface illumination. Samples for chlorophyll analysis were taken along with the 0800 and 2000 samples and the in situ samples. A brief summary of the methods of processing the samples and the results has been provided by M. Oguri of the University of Hawaii and is included as Appendix "A".

Oceanographic Studies

Water sampling.--A total of 51 oceanographic casts (including two at the IGY station off Oahu) were made from the Smith (table 1). Outside the primary albacore survey area, oceanographic observations were limited to the collection of data which would be sufficient to permit comparison of conditions with those observed during previous years. Also, the observations were planned so that the HBL data would extend and supplement those collected during the same period from vessels of the Seattle Biological Laboratory, which were operating near the Aleutian Islands and in the Bering Sea.

Outside the area the 13-bottle casts to 1,200 meters were made at approximately 90-mile intervals. Inside the albacore survey area the interval was shortened to permit a more detailed study of the geostrophic current structure. Except for the stations occupied on either side of the temperature front centered at 41°31'N., 175°07'W., the interval between stations ranged from 30 to 60 miles. The actual spacing depended to a large extent upon when they could best be worked into the operational schedule.

Samples for salinity, inorganic phosphate, and dissolved oxygen were drawn from each Nansen bottle. Surface salinities and inorganic phosphate samples were also collected at the location of between-station bathythermograph casts. The salinity samples were returned to HBL for analysis, and the dissolved oxygen and inorganic phosphate samples were analyzed aboard ship. The oceanographic station data are given in table 13 and those from the bathythermograph casts in table 14.

Surface salinity samples were taken at most locations of bathythermograph casts from the Paragon. The analyses were made at the Seattle Biological Laboratory. The results are listed in table 15.

Water temperature.--The recording thermograph aboard the Smith was operated continuously. Bathythermograph casts were made before and after each oceanographic cast and each longline set (see table 14 for station data and figs. 4-13 for profiles). On runs between stations, they were made at 30-mile intervals outside the albacore survey area and at intervals of 15 miles or less inside the area. In the latter case the interval was frequently shortened to make the casts coincide with troll catches, Secchi disc lowerings, or C-14 samples. At the front encountered at 41°30'N., 175°07'W., where the temperature increased from 61.5°F. to 63.5°F. in 4 miles along a north-south course, a series of BT casts were made at 1-mile intervals.

Thirty-six bathythermograph casts were made from the Paragon to a depth of 180 feet. All but one were at gill-net stations. The station data are given in table 15.

Meteorological observations.--Synoptic marine weather observations were made on the Smith at 0000, 0600, 1200, and 1800 GCT daily. They were recorded in the International Ship's Weather Code (U.S.W.B. 1954) and transmitted to either the U. S. Weather Bureau at San Francisco, California or Honolulu, Hawaii, whenever radio conditions permitted. The observations are listed in table 16.

Subsurface illumination observations.--Observations of subsurface illumination were made from the Smith with both the Schuler submarine photometer and the Secchi disc. Only the Secchi disc was used from the Paragon. The Schuler photometer and method of operation have been described by Callaway (1957). Lowerings were made once per day until the instrument failed at station 27. The results are listed in table 17.

Secchi disc observations from the Smith were made at approximately local noon each day when the weather permitted. Additional observations were made in the vicinity of the temperature front mentioned above. The results are included in table 1. Secchi disc lowerings from the Paragon were made at the location of bathythermograph casts (table 15).

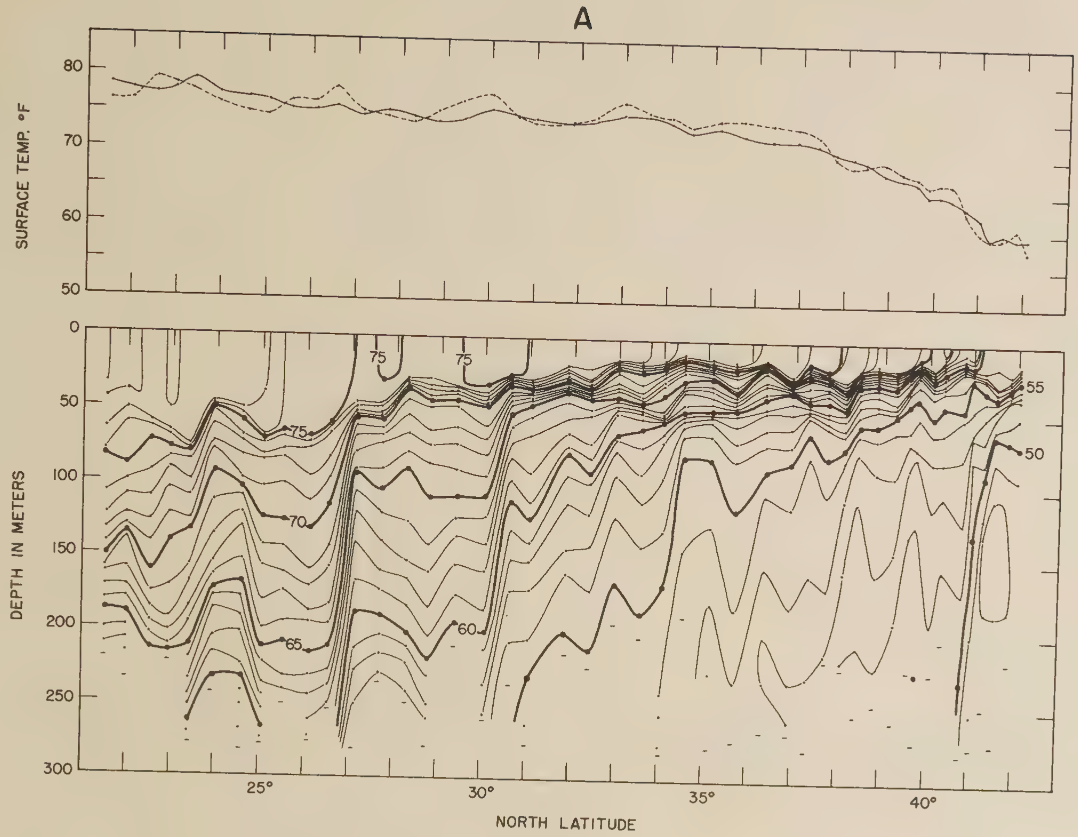
LABORATORY METHODS AND TECHNIQUES

Most of the procedures used in the analysis of the samples have been described in earlier reports. The dissolved oxygen analyses were made aboard the Smith by the standard Winkler method described in U. S. Navy Hydrographic Office Pub. 607 (1955).

The inorganic phosphate determinations were analyzed by the hydrazine sulphate modification of Denigi's method developed by Van Landingham (King et al. 1957). The determinations for stations 1 to 11 were made with the Automatic Servo-operated Photometer described by Wooster and Rakestraw (1951). After station 11 this instrument failed and a Beckman photometer was used.

The salinity determinations at HBL were made by a modification of Fajan's adsorption indicator method developed by Van Landingham (1957).

The reduction of the protected thermometer readings to true water temperature and the thermometric determination of the sampling depths were done using graphical methods described by La Fond (1951).



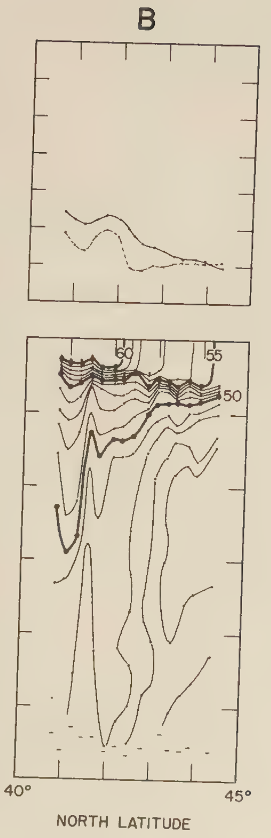
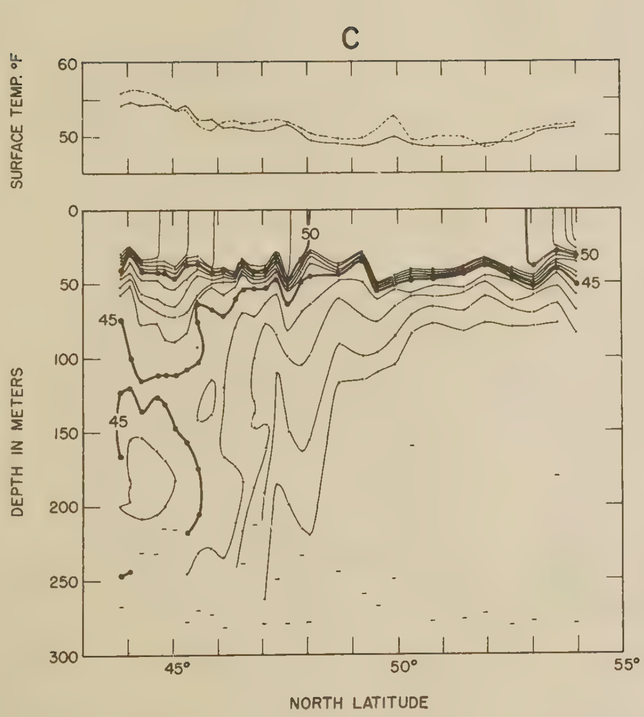
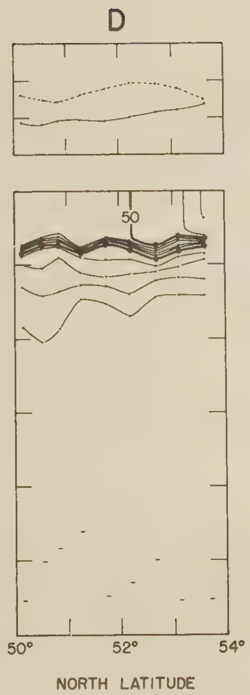


Figure 4.--Surface bucket-temperature (upper panel) and temperature-depth sections from bathythermograph observations (lower panel). Section A (see fig. 1) of Hugh M. Smith cruise 46, July-September 1958.

Figure 5.--Same along Section B (fig. 1).





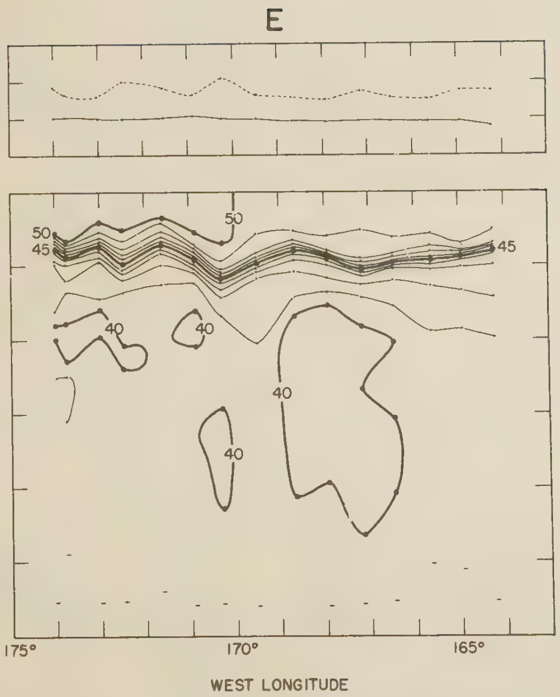
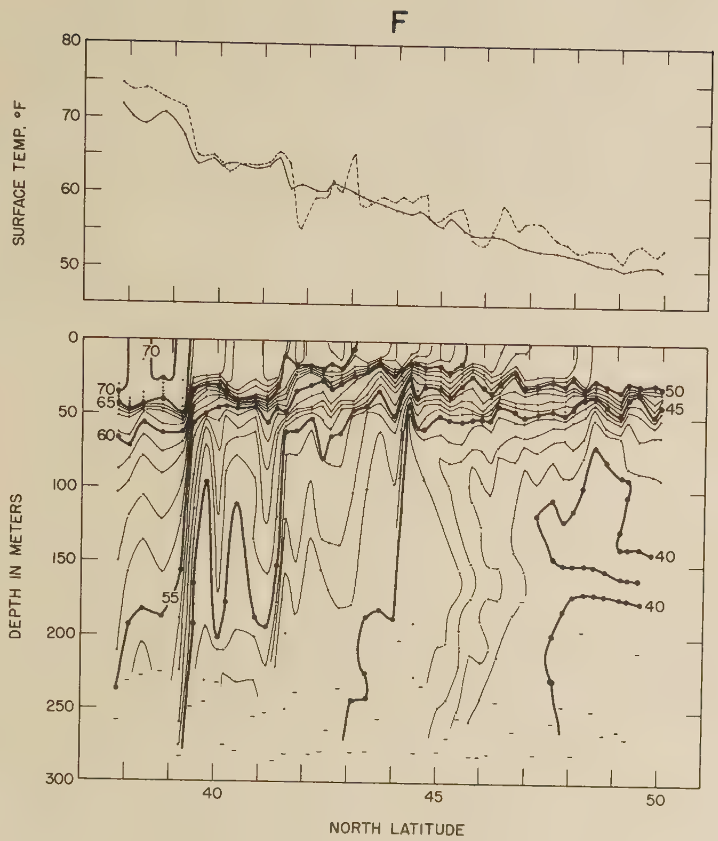


Figure 6.--Surface bucket-temperature (upper panel) and temperature-depth sections from bathythermograph observations (lower panel). Section C (see fig. 1) of *Hugh M. Smith* cruise 46, July-September 1958.

Figure 7.--Same along Section D (fig. 1).

Figure 8.--Same along Section E (fig. 1).



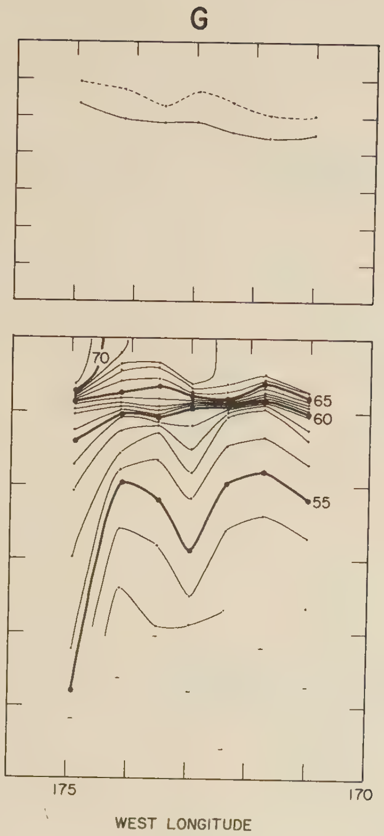
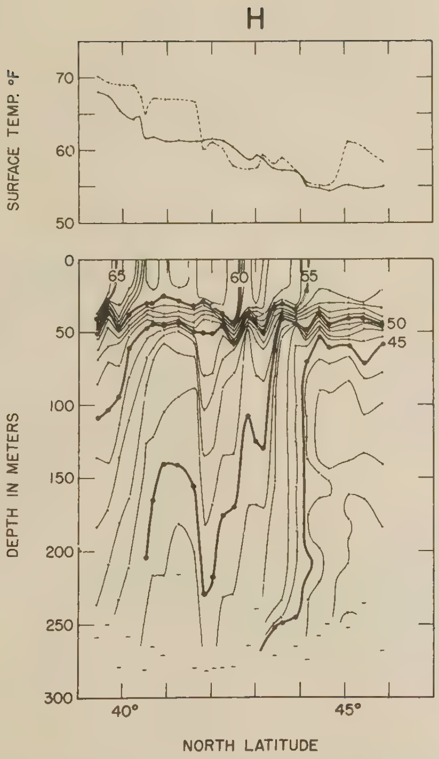
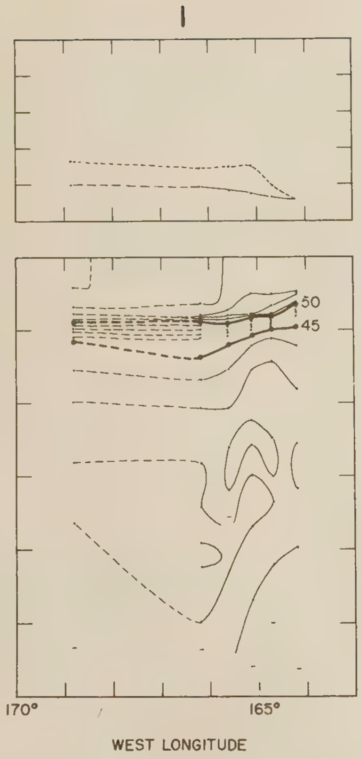


Figure 9.--Surface bucket-temperature (upper panel) and temperature-depth sections from bathythermograph observations (lower panel). Section F (see fig. 1) of Hugh M. Smith cruise 46, July-September 1958.

Figure 10.--Same along Section G (fig. 1).





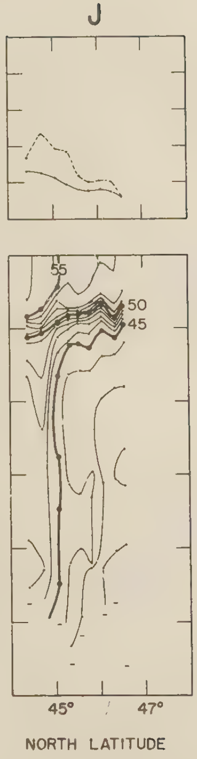


Figure 11.--Surface bucket-temperature (upper panel) and temperature-depth sections from bathythermograph observations (lower panel). Section H (see fig. 1) of *Hugh M. Smith* cruise 46, July-September 1958.

Figure 12.--Same along Section I (fig. 1).

Figure 13.--Same along Section J (fig. 1).

The processing of the data and the construction of the station curves given in table 13 were prepared using techniques described by Montgomery (1954), Montgomery and Wooster (1954), Stroup (1954), and King et al. (1957).

The zooplankton volumes given in table 12 were obtained by first removing all organisms over 5 cm. in length and all non-food organisms (King and Hida 1954) over 2 cm. in length and then measuring the wet, drained volume in the manner described by King and Demond (1953).

FUTURE PUBLICATION

It is expected that the data from Smith cruise 46 and the Paragon will be used as the basis for at least two future reports and parts of the data will be incorporated in other biological reports. A report discussing the commercial potentialities of the area is now being prepared by the authors of this report, and a report comparing the oceanographic conditions with those during the summer of 1955 (McGary et al. 1956) is contemplated. The results of the albacore stomach analyses will be used in a general study of the food of the albacore and the plankton data in oceanwide indicator organism studies.

PERSONNEL

Hugh M. Smith

- Barnes Collinson, Master
- James W. McGary, Field Party Chief
- Everet C. Jones, Fishery Research Biologist
- Reginald M. Gooding, Fishery Research Biologist
- Donald A. Thomson, Fishery Research Biologist
- Fred Hertlein III, Physical Science Aid
- Robert K. S. Lee, Research Assistant, University of Hawaii

M/V Paragon

- Harry J. Jacobsen, Master
- Joseph J. Graham, Fishery Research Biologist

Personnel processing samples and data (in addition to field parties)

- Mary Lynne Godfrey, Physical Science Technician (Oceanography)
- John W. Van Landingham, Physical Science Technician (Chemistry)
- Ella W. Mendiola, Physical Science Technician (Oceanography)
- Betty Ann L. Keala, Statistical Clerk

RECORDS

The following records were kept and are on file at the Honolulu Biological Laboratory, except as otherwise noted:

Hugh M. Smith

- Barograph records (at U. S. Weather Bureau Records Center, Asheville, N. C.)
- Chemical log sheets
- Deck log
- Gill net log
- Log sheet "A" (original oceanographic data)
- Log sheet "B" (bathythermograph data, original at Scripps Institution of Oceanography, duplicate at Honolulu Biological Laboratory)
- Longline log
- Midwater trawl log
- Occurrence of tuna schools, birds, and aquatic mammals
- Photometer log
- Plankton log and flowmeter calibration log
- Scientists' log
- Tagging record
- Thermograph charts
- Track chart
- Trolling log
- U. S. Weather Bureau Form 1210F (original at U. S. Weather Bureau Records Center, Asheville, N. C., duplicate at Honolulu Biological Laboratory)

M/V Paragon

- Deck log
- Gill net log
- Log sheet "B" (bathythermograph data, original at Scripps Institution of Oceanography, duplicate at Honolulu Biological Laboratory)
- Salinity records (original at Bureau of Commercial Fisheries Biological Laboratory, Seattle, Washington)
- Scientists' log
- Trolling log

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Table 1.--Summary of the types of observations (except C_{14}) made at *Hugh M. Smith* cruise 46 stations

Abbreviations used:

SD - Secchi disc	MWT - Isaacs-Kidd midwater trawl
GN - Gill net	NL - Night light
LL - Longline	Plk - Plankton tow

Sta. No.	Time GCT	Date 1958	Lat. N.	Long. W.	Hydro cast (m.)	SD (m.)	Photo-meter	GN	LL	60 m. Plk	140 m. Plk	Surf Plk 1 m.	Surf Plk 45 cm.	MWT	NL
1	0538	7/22	21°11'	158°19'	1400	-	-	-	-	-	-	-	-	-	-
2	0850	7/22	21°11'	158°19'	-	-	-	-	-	2	-	-	-	-	-
3	1238	7/22	21°11'	158°19'	500	-	-	-	-	-	-	-	-	-	-
4	0652	7/23	23°56'	158°33'	1200	-	-	-	-	-	x	x	-	-	-
5	1847	7/23	25°33'	158°34'	1200	-	-	-	-	-	-	-	-	-	-
6	2230	7/23	26°07'	158°38'	-	25	x	-	-	-	-	-	-	-	-
7	0613	7/24	27°08'	158°38'	1200	-	-	-	-	-	x	x	-	-	
8	1831	7/24	28°45'	158°44'	1200	-	-	-	-	-	-	-	-	-	
9	2245	7/24	29°29'	158°51'	-	35	x	-	-	-	-	-	-	-	-
10	0642	7/25	30°36'	158°56'	1200	-	-	-	-	-	x	x	-	-	-
11	1940	7/25	32°25'	158°50'	1200	-	-	-	-	-	-	-	-	-	-
12	2355	7/25	33°05'	158°50'	-	31	x	-	-	-	-	-	-	-	-
13	0726	7/26	34°01'	158°54'	1200	-	-	-	-	-	x	-	-	-	x
14	1939	7/26	35°44'	158°58'	1200	-	-	-	-	-	-	-	-	-	-
15	0000	7/27	36°24'	159°01'	-	18	x	-	-	-	-	-	-	-	-
16	0749	7/27	37°25'	159°09'	1200	-	-	-	-	-	x	x	-	-	x
17	1936	7/27	38°35'	159°13'	1200	-	-	-	-	-	-	-	-	-	-
18	0000	7/28	39°00'	159°14'	-	13	x	-	-	-	-	-	-	-	-
19	0735	7/28	39°40'	159°15'	1200	-	-	-	-	-	x	x	-	x	x
20	1915	7/28	40°11'	159°18'	-	15	x	-	-	-	-	-	-	-	-
21	2330	7/28	40°31'	159°18'	-	17	x	-	-	-	-	-	-	-	-
22	0535	7/29	40°49'	159°38'	1200	-	-	x	-	-	x	x	-	-	x
	1810	7/29	40°48'	159°39'	-	-	-	-	-	-	-	-	-	-	-
23	2100	7/29	41°05'	159°39'	-	17	x	-	-	-	-	-	-	-	-
24	2345	7/29	41°18'	159°39'	-	18	x	-	-	-	-	-	-	-	-
25	0300	7/30	41°30'	159°39'	-	18	x	-	-	-	-	-	-	-	-
26	0600	7/30	41°20'	159°56'	1200	-	-	x	-	-	x	x	-	x	x
	1645	7/30	41°20'	159°59'	-	-	-	-	-	-	-	-	-	-	-
27	1930	7/30	41°37'	159°58'	-	13	x	-	-	-	-	-	-	-	-
28	2330	7/30	42°03'	159°57'	-	16	x	-	-	-	-	-	-	-	-
29	0600	7/31	41°46'	159°24'	1200	-	-	x	-	-	x	x	-	-	x
	1700	7/31	41°44'	159°22'	-	-	-	-	-	-	-	-	-	-	-
30	1930	7/31	41°32'	159°04'	-	14	-	-	-	-	-	-	-	-	-
31	2330	7/31	41°13'	158°42'	-	14	-	-	-	-	-	-	-	-	-
32	0330	8/1	40°59'	158°27'	-	14	-	-	-	-	-	-	-	-	-
33	0555	8/1	41°09'	158°24'	1200	-	-	x	-	-	x	x	-	-	x
	1720	8/1	41°06'	158°22'	-	-	-	-	-	-	-	-	-	-	-
34	1930	8/1	41°22'	158°22'	-	13	-	-	-	-	-	-	-	-	-
35	0020	8/2	41°48'	158°22'	-	15	-	-	-	-	-	-	-	-	-
36	0315	8/2	42°04'	158°22'	-	15	-	-	-	-	-	-	-	-	-
37	0545	8/2	42°19'	158°22'	1200	-	-	x	-	-	x	x	-	-	x
	1730	8/2	42°20'	158°23'	-	-	-	-	-	-	-	-	-	-	-
38	1915	8/2	42°32'	158°26'	-	14	-	-	-	-	-	-	x	-	-
39	2330	8/2	43°02'	158°32'	-	16	-	-	-	-	-	-	-	-	-
40	0555	8/3	43°10'	158°47'	1200	-	-	x	-	-	x	x	-	-	x
	1740	8/3	43°12'	158°44'	-	-	-	-	-	-	-	-	-	-	-
41	0533	8/4	41°16'	158°57'	1200	-	-	-	-	-	-	-	-	-	-
42	1944	8/4	43°49'	159°55'	1200	-	-	-	-	-	-	-	-	-	-
43	0735	8/5	45°00'	159°23'	1200	-	-	-	-	-	-	-	-	-	-
44	1734	8/5	46°06'	159°40'	1200	-	-	-	-	-	-	-	-	-	-
45	0140	8/6	47°04'	159°44'	1200	12	-	-	-	-	-	-	-	-	-
46	0956	8/6	48°04'	159°42'	1200	-	-	-	-	-	x	x	-	-	-
47	2159	8/6	49°35'	159°45'	1200	16	-	-	-	-	-	-	-	-	-

Table 1.--Summary of the types of observations (except C 14) made at *Hugh M. Smith* cruise 46 stations (cont'd)

Sta. No.	Time GCT	Date 1958	Lat. N.	Long. W.	Hydro cast (m.)	SD (m.)	Photo-meter	GN	LL	60 m. Plk	140 m. Plk	Surf Plk 1 m.	Surf Plk 45 cm.	MWT	NL
48	0755	8/7	50°56'	159°48'	1200	-	-	-	-	-	x	x	-	-	-
49	2016	8/7	52°35'	159°56'	1200	13	-	-	-	-	-	-	-	-	-
50	0654	8/8	54°00'	159°55'	1200	-	-	-	-	-	x	x	-	-	x
51	1944	8/11	50°00'	174°03'	1200	-	-	-	-	-	-	-	-	-	-
52	0495	8/12	49°02'	174°36'	1200	14	-	-	-	-	-	-	-	-	-
53	1127	8/12	48°03'	174°45'	1200	-	-	-	-	-	x	x	-	-	-
54	1936	8/12	47°14'	174°56'	1200	17	-	-	-	-	-	-	-	-	-
55	0030	8/13	46°42'	174°59'	-	16	-	-	-	-	-	-	-	-	-
56	0555	8/13	46°12'	174°56'	1200	-	-	x	-	-	x	x	-	x	x
	1640	8/13	46°10'	174°56'	-	-	-	-	-	-	-	-	-	-	-
57	1915	8/13	46°01'	174°56'	-	17	-	-	-	-	-	-	-	-	-
58	2340	8/13	45°30'	174°56'	-	15	-	-	-	-	-	-	-	-	-
59	0430	8/14	45°04'	174°54'	-	17	-	-	-	-	-	-	-	-	-
60	0604	8/14	45°12'	174°53'	1200	-	-	x	-	-	x	-	-	-	x
	1900	8/14	-	-	-	18	-	-	-	-	-	-	-	-	-
	2345	8/14	-	-	-	17	-	-	-	-	-	-	-	-	-
	0130	8/15	45°08'	174°47'	- -	-	-	-	x	-	-	-	-	-	-
61	0635	8/15	44°39'	174°48'	-	-	-	-	-	-	-	-	-	-	-
	1745	8/15	44°31'	174°39'	-	-	-	x	-	-	-	-	-	-	x
62	1937	8/15	44°23'	174°40'	1200	-	-	-	-	-	-	-	-	-	-
63	0554	8/16	43°29'	174°48'	1200	-	-	x	-	-	x	x	-	-	x
	2015	8/16	-	-	-	14	-	-	-	-	-	-	-	-	-
	0320	8/17	43°23'	174°38'	-	13	-	-	x	-	-	-	-	-	-
64	0535	8/17	43°22'	174°43'	-	-	-	x	-	-	-	-	-	-	x
	1745	8/17	43°28'	174°40'	-	-	-	-	-	-	-	-	-	-	-
65	1910	8/17	43°20'	174°45'	-	13	-	-	-	-	-	-	-	-	-
66	0000	8/18	42°50'	175°02'	-	13	-	-	-	-	-	-	-	-	-
67	0529	8/18	42°47'	175°08'	1200	-	-	x	-	-	x	-	-	-	x
	1945	8/18	42°46'	175°08'	-	14	-	-	-	-	-	-	-	-	-
	0120	8/19	42°46'	175°08'	-	14	-	-	-	-	-	-	-	-	-
	0520	8/19	42°48'	175°03'	-	-	-	-	x	-	-	-	-	-	-
68	0617	8/19	42°48'	175°03'	-	-	-	x	-	-	-	x	-	-	x
	1815	8/19	42°42'	175°11'	-	-	-	-	-	-	-	-	-	-	-
69	0556	8/20	41°35'	175°08'	1200	-	-	-	-	-	x	x	-	-	x
70	1730	8/20	41°28'	175°06'	-	-	-	-	x	-	-	-	-	-	-
	1920	8/20	41°32'	175°08'	-	16	-	-	-	-	-	-	-	-	-
	2010	8/20	-	-	-	14	-	-	-	-	-	-	-	-	-
	2020	8/20	-	-	-	16	-	-	-	-	-	-	-	-	-
	2035	8/20	-	-	-	16	-	-	-	-	-	-	-	-	-
	2045	8/20	-	-	-	17	-	-	-	-	-	-	-	-	-
	2055	8/20	-	-	-	18	-	-	-	-	-	-	-	-	-
	2105	8/20	-	-	-	19	-	-	-	-	-	-	-	-	-
	2300	8/20	-	-	-	-	-	-	-	-	-	-	(5)	-	-
	0300	8/21	41°28'	175°06'	-	-	-	-	-	-	-	-	-	-	-
71	2236	8/22	41°33'	175°02'	1200	17	-	-	-	-	-	-	-	-	-
72	0030	8/23	41°39'	175°06'	-	13	-	-	-	-	-	-	-	-	-
73	0120	8/23	41°43'	175°09'	-	11	-	-	-	-	-	-	-	-	-
74	0342	8/23	41°52'	175°16'	1200	16	-	-	-	-	-	-	x	-	-
75	0540	8/23	41°52'	175°16'	-	-	-	-	-	-	x	-	-	-	-
76	0655	8/23	41°35'	175°01'	-	-	-	x	-	-	-	-	-	-	x
	1745	8/23	41°35'	175°09'	-	-	-	-	-	-	-	-	-	-	-
77	1920	8/23	41°28'	175°10'	-	15	-	-	-	-	-	-	-	-	-
78	0000	8/24	40°56'	175°10'	-	16	-	-	-	-	-	-	-	-	-
79	0436	8/24	40°29'	175°11'	1200	-	-	-	-	-	-	-	-	-	-
80	1547	8/24	39°14'	175°10'	1200	-	-	-	-	-	-	-	-	-	-
81	1900	8/24	38°52'	175°06'	-	18	-	-	-	-	-	-	-	-	-
82	0102	8/25	37°58'	174°58'	1200	18	-	-	-	-	-	-	-	-	-

Table 1.--Summary of the types of observations (except C 14) made at Hugh M. Smith cruise 46 stations (cont'd)

Sta. No.	Time GCT	Date 1958	Lat. N.	Long. W.	Hydro cast (m.)	SD (m.)	Photo-meter	GN	LL	60 m. Plk	140 m. Plk	Surf Plk 1 m.	Surf Plk 45 cm.	MWT	NL
83	2154	8/25	39°25'	170°58'	1200	18	-	-	-	-	-	-	-	-	-
84	0130	8/26	39°59'	170°50'	-	16	-	-	-	-	-	-	-	-	-
85	0555	8/26	39°50'	170°52'	-	-	-	x	-	-	x	x	-	-	x
	1700	8/26	39°51'	170°46'	-	-	-	-	-	-	-	-	-	-	-
86	1925	8/26	40°04'	170°41'	-	17	-	-	-	-	-	-	-	-	-
87	2320	8/26	40°28'	170°32'	1200	15	-	-	-	-	-	-	-	-	-
88	0550	8/27	40°15'	170°16'	-	-	-	x	-	-	x	x	-	-	x
	1915	8/27	40°13'	170°20'	-	23	-	-	-	-	-	-	-	-	-
	0130	8/28	-	-	-	23	-	-	-	-	-	-	-	-	-
	0320	8/28	40°13'	170°20'	-	-	-	-	x	-	-	-	-	-	-
89	2016	8/28	41°26'	170°39'	1200	18	-	-	-	-	-	-	-	-	-
90	0538	8/29	42°21'	170°12'	1200	-	-	x	-	-	x	x	-	-	x
	2010	8/29	-	-	-	17	-	-	-	-	-	-	-	-	-
	2300	8/29	42°13'	170°11'	-	16	-	-	-	-	-	-	-	-	-
	0335	8/30	42°17'	170°11'	-	-	-	-	x	-	-	-	-	-	-
91	0700	8/30	42°50'	169°57'	-	-	-	x	-	-	x	x	-	-	x
	1735	8/30	42°46'	170°03'	-	-	-	-	-	-	-	-	-	-	-
92	1800	8/30	42°56'	169°55'	-	20	-	-	-	-	-	-	-	-	-
93	2336	8/30	43°18'	169°39'	1200	18	-	-	-	-	-	-	-	-	-
94	0510	8/31	43°56'	169°30'	-	-	-	-	-	-	x	x	-	-	-
95	0740	8/31	44°06'	169°20'	1200	-	-	-	-	-	-	-	-	-	-
96	0534	9/1	45°46'	168°46'	1200	-	-	-	-	-	x	x	-	-	x
97	1900	9/1	45°57'	166°16'	-	11	-	-	-	-	-	-	-	-	-
98	0420	9/2	46°34'	164°44'	1200	-	-	-	-	-	x	-	-	-	x
	1930	9/2	-	-	-	17	-	-	-	-	-	-	-	-	-
	0014	9/3	46°28'	164°29'	-	15	-	-	-	-	-	-	-	-	-
	0215	9/3	46°33'	164°30'	-	-	-	-	x	-	-	-	-	-	-
99	0813	9/3	45°38'	164°47'	1200	-	-	-	-	-	-	-	-	-	x
100	1925	9/3	44°58'	165°04'	-	13	-	-	-	-	-	-	-	-	-
101	2210	9/3	44°43'	165°04'	1200	-	-	-	-	-	-	-	-	-	-

Table 2.--List of common and scientific names and abbreviations used in HBL data for fish encountered during cruise 46 of the *Hugh M. Smith* and that of the M/V *Paragon*

ABBREVIATION	COMMON NAME	SCIENTIFIC NAME
AL	Albacore tuna	*Thunnus germo* (Lacépède)
-	Boar fish	Histiopteridae
-	Broadbill swordfish	*Xiphias gladius* Linnaeus
DO	Dolphin	*Coryphaena hippurus* Linnaeus
GB	Great blue shark	*Prionace glauca* (Linnaeus)
LF	Lancet fish	*Alepisaurus borealis*(Gill)
-	Lantern fish	Myctophidae
MS	Mackerel shark	*Lamna ditropis* Hubbs and Follett
MKS	Mako shark	*Isurus glaucus* Muller and Henle
-	Pomfret	*Brama raii* (Bloch)
SJ	Skipjack	*Katsuwonus pelamis* (Linnaeus)
-	Saury	*Cololabis* sp.
WA	Wahoo	*Acanthocybium solandri* (Cuvier and Valenciennes)

Table 3.--Summary of gill-net catches, Hugh M. Smith cruise 46

Sta. No.	Date, 1958 (GCT)	Lat. N.	Long. W.	Surf. Temp. 1/ (°F.)		AL	Sharks	Misc.	Remarks
				S	F				
22	7/29	40°49'	159°38'	63.1	63.3	0	41 GB	0	
26	7/30	41°20'	159°59'	61.7	61.5	0	4 GB	0	
29	7/31	41°46'	159°24'	58.8	58.6	0	11 GB	2 squid	
33	8/1	41°09'	158°24'	61.4	61.5	4	38 GB	0	
37	8/2	42°20'	158°23'	59.8	59.2	0	6 GB 1 MS	0	
40	8/3	43°10'	158°47'	56.7	56.4	5	1 GB 1 MS 1 Basking	4 Bramids 1 Boar fish 3 squid	1 Alb. lost
56	8/13	46°12'	174°56'	54.7	54.4	0	0	11 Bramids	1 Alb. lost
60	8/14	45°12'	174°53'	56.2	55.9	3	1 GB 2 MS	26 Bramids 1 squid	1 Alb. lost
61	8/15	44°31'	174°39'	57.8	57.1	0	10 GB	1 Bramid 1 squid	(net badly tangled because of seas)
63	8/16	43°29'	174°48'	59.0	58.9	26	1 MS 18 GB	1 Bramid 2 squid	1 Alb. lost
64	8/17	43°22'	174°43'	58.8	58.8	3	7 GB	1 Bramid 2 squid	
67	8/18	42°47'	175°08'	61.0	60.8	49	22 GB 1 MS	3 Bramid 3 squid 1 porpoise	(right whale)
68	8/19	42°48'	175°03'	61.4	60.8	7	8 MS 1 MS	0	2 Bramids lost
76	8/23	41°35'	175°09'	61.9	61.2	0	0	0	
85	8/26	39°50'	170°52'	65.7	65.3	0	0	7 SJ 2 squid	1 SJ lost
86	8/27	40°15'	170°16'	63.2	62.8	0	0	13 SJ 1 Brd. bill swordfish	
90	8/29	42°21'	170°12'	61.1	60.5	0	5 GB	0	
91	8/30	42°50'	169°57'	58.7	58.7	0	14 GB	2 Bramids	
98	9/2	46°34'	164°44'	53.3	53.0	0	0	17 Bramids 2 Fur seals	1 Bramid lost
Total 19						97		20 SJ	4 Alb. lost 1 SJ lost

1/ S indicates start, F indicates finish of fishing.

Table 4.--Summary of gill-net catches, M/V *Paragon*

Sta. No.	Date, 1958	Position		Surf. Temp. (°F.)	Albacore	GB	Miscellaneous
		Latitude N.	Longitude W.				
1	7/26	41°40'	157°11'	62.7	145	158	--
2	7/27	41°44'	156°58'	61.9	133	144	4 broadbill swordfish
3	7/28	42°20'	156°49'	60.3	119	165	--
4	7/29	41°49'	157°09'	61.8	40	123	--
5	7/30	41°43'	157°03'	62.0	30	156	--
6	7/31	41°38'	157°20'	62.0	13	116	--
7	8/1	42°31'	157°08'	57.7	22	18	--
8	8/2	42°56'	158°13'	57.4	20	--	1 un. tuna 4 porpoise
9	8/4	41°16'	161°24'	60.8	1	27	2 un. tuna
10	8/5	41°36'	162°40'	60.2	3	17	2 broadbill 1 porpoise
11	8/6	41°27'	163°37'	61.4	0	53	--
12	8/7	42°12'	163°30'	58.9	24	19	several boarfish 2 bramids
13	8/8	42°11'	162°10'	59.2	14	22	2 broadbill
14	8/9	42°15'	160°51'	59.4	22	16	3 un. tuna 2 broadbill
15	8/10	41°57'	159°12'	58.5	103	72	1 un. tuna
16	8/12	42°06'	159°22'	57.7	18	31	1 porpoise
17	8/13	41°50'	159°23'	58.7	41	214	--
18	8/14	42°02'	158°57'	59.7	62	--	2 un. tuna 1 broadbill
19	8/15	42°24'	158°38'	58.7	72	1	--
20	8/16	42°24'	158°35'	58.8	60	42	--
21	8/17	42°34'	158°27'	58.3	19	--	--
22	8/20	42°26'	158°16'	58.7	45	61	2 un. tuna
23	8/22	42°30'	157°56'	58.7	12	112	1 broadbill
24	8/23	42°02'	159°05'	57.5	5	90	1 un. tuna 2 broadbill
25	8/24	42°06'	158°45'	59.5	46	123	1 porpoise
26	8/25	41°38'	158°25'	59.9	28	8	--
27	8/26	41°43'	157°22'	63.0	183	18	2 broadbill
28	8/27	41°45'	157°09'	64.0	227	40	--
29	8/28	41°48'	156°52'	63.5	55	30	--
30	8/29	41°46'	157°09'	62.7	54	22	--
				TOTAL	1,617	1,897	

Table 5.--Summary of surface trolling, *Hugh M. Smith*, cruise 46

Date, 1958	Within Positions				Hours Trolled	Lines	Catch	Fork length (cm.)	Ident. lost fish	AL tagged	Speed (knots)
	Lat. N.	Long. W.	Lat. N.	Long. W.							
7/22	21°34'	158°25'	23°55'	158°33'	14.5	2	--	--	--	--	9.3
7/23	25°03'	158°32'	27°07'	158°38'	12.5	2	1 WA	145.0	--	--	9.3
7/24	28°17'	158°40'	30°36'	158°56'	12.0	2	--	--	--	--	9.0
7/25	31°53'	158°52'	34°01'	158°54'	12.0	2	--	--	1 DO	--	9.5
7/26	35°12'	158°57'	37°24'	159°08'	12.0	2	1 DO	91.7	--	--	9.5
7/27	38°15'	159°12'	39°40'	159°15'	13.0	5	--	--	--	--	6.5
7/28	39°49'	159°18'	40°49'	159°31'	15.0	5	--	--	--	--	6.0
7/29	40°48'	159°39'	41°20'	159°56'	11.0	5	1 AL	--	--	1	6.0
7/30	41°21'	159°59'	41°46'	159°24'	12.0	5	1 AL	72.6	--	1	6.0
7/31	41°45'	159°23'	41°09'	158°24'	12.5	5	--	--	--	--	6.0
8/1	41°06'	158°22'	42°19'	158°22'	12.0	5	1 AL	85.0	--	1	6.0
8/2	42°21'	158°23'	43°10'	158°46'	12.0	5	1 AL	67.5	--	--	6.0
8/3	43°12'	158°44'	44°16'	158°57'	11.5	5	--	--	--	--	6.0
8/4	43°54'	159°38'	45°00'	159°23'	14.5	5	--	--	--	--	6.0
8/5	46°07'	159°40'	47°49'	159°42'	12.0	3	--	--	--	--	9.0
8/7	52°36'	159°56'	54°00'	159°55'	9.0	3	--	--	--	--	9.0
8/9	50°14'	164°26'	50°07'	166°24'	9.0	3	--	--	--	--	9.0
8/12	47°33'	174°53'	46°12'	174°56'	10.5	5	--	--	--	--	6.0
8/13	46°10'	174°56'	45°11'	174°54'	11.0	5	--	--	--	--	6.0
8/14	45°08'	174°47'	44°39'	174°44'	7.0	5	--	--	--	--	6.0
8/15	44°29'	174°39'	43°44'	174°47'	9.0	4	--	--	1 AL	--	6.0
8/16	43°22'	174°44'	43°22'	174°43'	3.5	5	--	--	--	--	5.0
8/17	43°28'	174°40'	42°47'	175°07'	11.0	5	3 AL	68.0 72.2 71.2	--	--	6.0
8/18	42°46'	175°08'	42°46'	175°08'	3.0	5	--	--	--	--	6.0
8/19	42°41'	175°11'	41°35'	175°08'	10.5	4	--	--	--	--	6.0
8/20	41°32'	175°08'	41°19'	175°06'	4.0	5	1 AL	87.0	--	--	6.0
8/21	41°30'	174°59'	41°50'	174°56'	10.0	5	--	--	--	--	6.0
8/22	41°47'	175°01'	41°52'	175°16'	7.0	6	--	--	--	--	6.0
8/23	41°35'	175°09'	40°30'	175°11'	9.5	5	1 MKS	--	--	--	6.0
8/24	39°13'	179°10'	38°21'	173°57'	13.0	2	--	--	--	--	9.0
8/25	39°16'	171°44'	39°50'	170°52'	10.5	5	--	--	--	--	9.0
8/26	39°53'	170°46'	40°15'	170°17'	9.5	5	--	--	--	--	6.5
8/27	40°15'	170°19'	40°47'	170°18'	6.0	2	--	--	--	--	6.0
8/28	41°26'	170°39'	42°21'	170°12'	8.0	5	4 AL	68.4 90.6 83.9 73.2	--	--	6.0
8/30	42°45'	170°03'	43°56'	169°30'	10.0	5	--	--	--	--	6.0
8/31	44°39'	168°33'	45°31'	168°45'	8.0	3	--	--	--	--	6.0
9/1	45°58'	166°37'	46°34'	164°44'	10.0	5	--	--	--	--	9.0
9/2	46°28'	164°29'	46°05'	164°31'	5.5	3	--	--	--	--	6.5
9/3	45°02'	165°06'	44°18'	164°32'	11.0	3	1 AL	63.9	--	--	6.0
9/4	41°25'	163°43'	40°48'	163°39'	3.5	2	--	--	--	--	10.0
9/5	38°35'	163°22'	36°27'	162°50'	12.0	3	2 DO	84.0 84.0	--	--	10.0
9/6	34°49'	162°12'	33°04'	161°33'	11.0	2	--	--	--	--	10.0
9/7	31°03'	160°48'	29°12'	160°23'	11.0	2	1 DO	78.8	--	--	10.0
9/8	27°03'	158°43'	25°22'	159°08'	11.0	2	1 DO	65.5	--	--	9.5

Table 6.--Summary of surface trolling catches, M/V Paragon

Date, 1958	Estimated position of catch		Hours trolled	Lines trolled	AL catch	Fork lengths (cm.)
	N. Lat.	W. Long.				
7/20	47°48'	138°53'	12.0	4	1	68.4
7/23	46°39'	153°07'	15.0	4	1	65.3
7/24	44°45'	155°35'	11.0	4	2	67.7, 70.2
7/25	43°42'	157°09'	14.5	5	3	70.0,67.7, 67.0
7/26	41°37'	157°07'	13.5	6	6	78.9, 76.9, 80.2, 69.4, 70.5, 53.6
7/28	41°53'	156°56'	7.0	8	38	67.2, 71.6, 68.8, 64.2, 66.6, 53.5, 55.7, 66.5, 69.2, 67.8, 61.4, 52.3, 55.5, 55.5, 53.4, 53.5; 10 AL 50-60 (est.), 12 AL 60-70 (est.)
7/30	41°43'	157°05'	5.0	8	37	52.5, 54.5, 64.5, 66.8, 67.1, 68.1, 68.5, 68.8, 68.9, 68.9, 69.3, 69.5, 69.7, 69.8, 71.3, 72.3, 72.8, 77.6, 83.4, 92.0; 17 not measured
7/31	41°43'	157°03'	4.0	8	4	66.5, 67.7, 69.3, 63.8
8/4	41°29'	159°52'	10.5	6	6	51.7, 52.5, 69.7, 80.3, 73.3, 78.2
8/7	41°45'	163°38	7.0	6	2	69.4, 69.4
8/10	41°58'	159°03'	7.5	6	3	68.9, 63.5, 66.2
8/12	42°04'	159°17'	3.5	6	2	70.5, 64.7
8/13	41°45'	159°15'	8.5	8	1	63.5
8/15	42°23'	159°01'	3.0	8	3	76.3, 67.4, 76.5
8/17	42°20'	158°11'	7.5	8	15	65.5, 67.8, 71.0, 69.9, 68.5, 71.5, 54.8, 56.2, 53.5, 68.2, 65.6, 68.2, 68.1, 65.4, 68.3
8/20	42°41'	157°54'	3.5	8	1	66.1
8/21	42°34'	157°55'	5.5	8	15	65.4, 65.6, 54.5, 67.3, 68.8, 67.2, 67.4, 67.2, 82.0, 68.7, 62.7, 66.5, 65.3, 69.3, 67.8
8/24	42°06'	159°13'	6.0	8	6	67.2, 65.4, 69.2, 62.8, 54.0, 66.9
8/26	41°33'	157°37'	7.5	8	3	54.4, 66.5, 70.0
8/27	41°35'	157°14'	6.0	8	35	67.1, 66.2, 74.1, 69.3, 67.9 50.5, 64.7, 69.1, 71.8, 71.6, 63.3, 69.1, 71.0, 67.6, 69.5, 53.2, 50.7; 18 not measured
8/28	41°50'	156°59'	3.5	8	17	53.8, 52.7, 55.7, 54.1, 68.4, 66.7, 67.2, 69.1, 62.2, 52.8, 65.1, 50.4, 53.5, 52.3, 69.8, 51.7, 53.1
8/29	41°50'	157°00'	7.5	8	16	52.0, 54.7, 68.8, 65.3, 54.2, 52.8, 55.8, 64.7, 53.7, 52.9, 67.1, 51.3, 53.5, 52.7, 53.4, 74.6
8/30	42°06'	155°40'	7.5	8	1	55.3
8/31	42°33'	153°15'	9.0	6	3	69.9, 52.2, 54.0
9/1	43°34'	148°21'	13.0	6	2	54.2, 53.8
9/5	47°34'	128°28'	2.0	8	10	55.6, 54.7, 55.6, 56.1, 53.2, 54.2, 53.5, 53.3, 53.7, 54.3

Table 7.--Summary of longline catches, Hugh M. Smith cruise 46

Sta. No.	Date, 1958 GCT (Start)	Lat. N.	Long. W.	Surf. temp.[1] (°F.)		AL	Sharks	Misc.	Remarks
				S	F				
60	8/14	45°08'	174°47'	55.9	56.7	0	27 GB	0	
63	8/16	43°23'	174°38'	58.9	59.1	0	41 GB 1 MS	0	
67	8/18	42°48'	175°03'	60.8	61.4	2	40 GB 2 MS	0	AL fork lengths 85.9 cm. 90.8 cm.
70	8/20	41°28'	175°06'	61.5 63.5	61.6 63.3	0	18 GB 1 MKS	0	Line set across a front
88	8/27	40°13'	170°20'	62.9	63.1	0	28 GB	0	
90	8/29	42°13'	170°11'	60.5	61.2	0	66 GB	1 Alepisaurus (head only)	
98	9/2	46°28'	164°29'	53.0	53.3	0	1 GB 1 MS	2 Alepisaurus	

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[1] S indicates start; F indicates finish.

Table 8.--Length frequency distribution, by stations, of albacore caught by the gill net, *Hugh M. Smith* cruise 46

Length (cm.)	Station No.						Total
	32	40	60	63	67	68	
50	-	-	-	-	-	-	-
51	1	-	-	1	-	-	2
52	-	-	-	-	3	-	3
53	-	-	-	1	6	-	7
54	1	-	-	1	4	3	9
55	-	-	-	4	10	2	16
56	1	-	-	1	3	-	5
57	-	-	-	-	1	-	1
58	-	-	-	-	-	1	1
59	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-
61	-	-	-	-	-	-	-
62	-	-	-	1	-	-	1
63	-	-	-	-	-	-	-
64	-	-	-	-	-	-	-
65	-	-	-	-	1	-	1
66	-	2	-	1	-	-	3
67	-	-	1	-	3	-	4
68	-	1	-	4	3	-	8
69	-	-	-	5	2	-	7
70	-	-	1	1	4	-	6
71	-	1	1	1	3	-	6
72	-	-	-	1	1	-	2
73	-	-	-	1	1	-	2
74	-	-	-	1	1	-	2
75	-	-	-	-	-	-	-
76	-	-	-	-	2	-	2
77	-	-	-	-	1	-	1
78	-	-	-	-	-	-	-
79	-	-	-	1	-	-	1
80	-	-	-	-	-	-	-
81	-	-	-	-	-	-	-
82	-	-	-	-	-	-	-
83	-	-	-	-	1	-	1
84	-	-	-	1	-	-	1
85	-	-	-	-	-	-	-
86	-	-	-	-	-	-	-
87	-	-	-	-	-	-	-
88	-	-	-	-	-	1	1
89	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-
Total	3	4	3	26	50	7	93

Table 9.--Length frequency distribution, by stations, of albacore caught by the gill net, M/V *Paragon*

Length (cm.)	Station Number																												Total
	1	2	3	4	5	6	7	8	10	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	3
52	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	3
53	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	4
54	-	-	-	7	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	9
55	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
56	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	5
57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	2
61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	2
62	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
63	-	1	-	-	-	-	3	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	7
64	1	-	3	-	-	-	-	-	-	-	-	3	-	-	3	-	-	-	-	1	-	1	1	-	1	1	1	1	17
65	1	1	-	-	2	-	1	-	-	1	-	-	-	1	3	1	1	-	-	1	1	-	2	-	1	-	1	2	20
66	-	4	4	-	2	-	3	3	-	-	1	2	1	-	2	1	-	1	-	3	-	1	5	3	1	2	2	4	45
67	-	5	6	-	2	-	4	6	1	3	1	2	3	3	6	7	4	2	1	5	2	-	4	3	2	4	1	5	82
68	1	2	6	-	3	2	1	2	-	1	1	-	2	2	2	6	5	3	2	-	1	-	7	1	5	8	5	6	74
69	4	4	1	-	1	2	2	1	-	2	4	2	4	2	2	5	1	-	2	3	-	-	3	3	7	4	5	2	66
70	1	2	2	1	3	1	3	3	-	3	1	1	4	2	4	2	5	6	2	7	1	-	-	2	2	11	6	2	77
71	2	3	1	-	1	-	1	1	-	3	2	2	1	-	10	3	3	1	1	1	2	-	-	-	3	6	-	1	48
72	2	-	-	-	2	1	1	-	-	4	1	3	1	2	1	3	4	2	-	2	-	-	-	1	4	3	-	1	38
73	1	-	-	-	-	1	1	-	1	3	-	3	2	1	2	1	-	1	-	-	1	-	2	-	-	-	-	2	22
74	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	1	1	-	-	-	2	-	-	1	-	8
75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1	-	-	-	-	-	-	-	-	3
76	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
77	-	1	-	-	1	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	7
78	1	-	-	-	-	-	-	1	-	-	-	-	1	1	2	-	1	1	-	-	-	-	-	-	-	-	2	-	10
79	1	2	-	-	-	-	-	-	-	1	-	-	2	1	1	-	3	-	1	-	1	-	1	1	-	-	1	-	16
80	2	-	1	-	-	-	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	-	2	1	1	-	-	-	10
81	2	2	-	-	2	1	-	-	-	-	-	-	2	-	-	-	1	1	-	-	-	-	1	-	-	-	1	-	13
82	4	2	-	-	1	2	-	1	-	3	-	1	2	1	-	-	-	-	-	-	-	-	5	1	1	-	2	-	26
83	2	-	1	-	2	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	1	-	3	1	-	-	1	-	13
84	2	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	5
85	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	3
86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	1	-	-	-	3
87	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	2
88	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	1	3
89	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	3
90	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1
92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	2
93	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
96	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Total	30	30	27	16	25	11	21	19	3	24	11	25	30	16	39	31	30	24	10	26	12	5	42	24	30	39	30	30	660

Table 10.--Summary of night light observations on the abundance of saury and squid, Hugh M. Smith cruise 46

Sta. No.	Date, 1958	Zone time	Position		Saury		Squid		Type of light 1/	Surface temp. (°F.) 2/
			Lat. N.	Long. W.	Number	Size (inches)	Number	Size (inches)		
13	7/25	2000-2045	34°01'	158°54'	0	-	2	12	S	74.7
					-	-	2	4-6	S	-
16	7/26	2030-2100	37°25'	159°09'	-	-	-	-	S	71.8
19	7/28	0130	39°49'	159°18'	-	-	1	12	C	66.8
22	7/28	2115-2240	40°49'	159°38'	4	10-12	-	-	C	63.1
26	7/29	2300-0000	41°20'	159°56'	6	12	1	3	S&C	61.3
					2	2.5	-	-	S&C	-
29	7/30	2130-2330	41°46'	159°34'	25	3	3	4	S&C	58.7
					1	10	-	-	S&C	-
33	7/31	1930-2020	41°09'	158°24'	25-30	10-12	2	12	C	61.4
		2145-2210	41°09'	158°24'	1	10	-	-	C	-
					4	3	-	-	S&C	-
37	8/1	2200-2245	42°19'	158°22'	3	8-10	1	12	S&C	59.8
					6	3	3	6	S&C	-
40	8/2	2215-2230	43°10'	158°47'	3	3	-	-	C	56.7
50	8/7	2133-2200	54°00'	159°55'	-	-	-	-	S	52.3
56	8/12	2300-0200	46°12'	174°56'	200-300	7-11	4	10-16	S&C	54.7
60	8/13	2300-2345	45°12'	174°53'	50-75	6-8	4	6	S&C	55.2
	8/14	0130-0245	45°12'	174°53'	200-300	6-8	2	28-30	C	-
					-	-	5	6-12	C	-
					-	-	2	18-24	C	-
61	8/14	2100-0000	44°39'	174°48'	50-100	6-8	-	-	S&C	57.8
					6	10-11	25	3-6	S&C	-
					-	-	3-4	18	S&C	-
	8/15	0200	44°39'	174°48'	100-200	6-8	-	-	C	-
63	8/15	2130-0000	43°29'	174°48'	20-50	6	2	3	S	59.0
64	8/17	0130	43°22'	174°43'	2-3	?	6	12	C	58.8
67	8/17	2100-2200	42°48'	175°08'	10	11	1	12	S	61.0
	8/18	0130	42°48'	175°08'	-	-	6	large	C	-
68	8/19	0130	42°48'	175°02'	few	?	1	?	C	61.4
69	8/19	2230-2245	41°35'	175°08'	3-4	10-12	6	12-16	S&C	61.5
	8/20	0130	41°35'	175°08'	11	12	?	small	C	-
76	8/22	2200-0000	41°35'	175°10'	3	2-5	3-4	3	S&C	61.9
			41°35'	175°10'	-	-	4-5	12	S&C	-
	8/23	0100-0130	41°35'	175°10'	5-6	10-12	10	12	C	-
85	8/25	2300	39°53'	170°46'	2-3	12	few	8-12	C	66.7
88	8/26	2130-2230	40°20'	170°16'	3	12	-	-	C	63.2
	8/27	0130-0200	40°15'	170°16'	7	11.5-13.5	2	19-21	C	-
		0230	40°15'	170°16'	5	12	-	-	C	-
90	8/28	2230-0000	42°21'	170°12'	-	-	-	-	S	61.1
91	8/29	2100-2300	42°46'	170°03'	1	1.5	1	24	S&C	56.7
96	8/31	1800-2045	45°46'	168°46'	3-4	10	-	-	C	55.0
98	9/1	2230-0000	46°34'	164°44'	100-200	3-12	12-15	6	S&C	53.3
99	9/2	2125-2214	45°38'	164°47'	10-15	12	2-3	24	C	54.0

1/ S=one 300-watt light submerged to 1 meter; C=vessel's cargo lights.

2/ Taken from the BT prior to the station.

Table 11.--Record of daily sightings of bird flocks, scattered birds, fish schools, and aquatic mammals, *Hugh M. Smith* cruise 46

U - unidentified
SK - shark
W - whale
P - porpoise

SW - sperm whale
SJ - skipjack
KW - killer whale
FS - fur seal

S - small
M - medium
L - large
Und - undetermined

Date, 1958	Noon position		Flocks									Scattered birds														Flying fish	Tuna schools	Aquatic mammals
			Total No.	Number of birds			Species comprised																					
	Lat. N.	Long. W.		< 10	10-50	> 50	Booby	Sea gull	Frigate bird	Tern	Petrel or shearwater	Black-footed albatross	Laysan albatross	Petrel or shearwater	Booby	Tern	Frigate bird	Tropic bird	Storm petrel	Sea parrot	Puffin	Snipe	Jaeger	Sea gull	Unidentified			
7/22	22°40'	158°31'	4	-	1	3	-	1	2	4	4	-	-	15	-	20	1	7	7	-	-	-	-	-	-	-	L-SJ Und-U M-U	W-1
7/23	25°59'	158°37'	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	4	-	-	-	-	-	-	-	3	-	-
7/24	29°20'	158°49'	-	-	-	-	-	-	-	-	-	5	-	10	-	1	-	1	3	-	-	-	-	-	-	-	-	-
7/25	32°56.7'	158°49'	-	-	-	-	-	-	-	-	-	8	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	W-1
7/26	36°14'	159°00'	-	-	-	-	-	-	-	-	-	22	-	6	-	-	-	1	2	-	-	-	-	-	-	-	-	-
7/27	38°53'	159°13'	-	-	-	-	-	-	-	-	-	37	-	20	-	22	-	-	73	-	-	-	2	-	-	-	-	-
7/28	40°31'	159°18'	-	-	-	-	-	-	-	-	-	71	-	17	5	64	-	-	48	-	-	4	-	-	-	-	-	-
7/29	41°14'	159°39'	1	-	1	-	-	-	-	-	1	51	-	8	-	1	-	-	42	-	-	-	1	-	-	-	-	S-2
7/30	41°58'	159°57'	-	-	-	-	-	-	-	-	-	62	-	16	-	20	-	-	19	-	-	-	-	3	-	-	-	-
7/31	41°15'	158°43'	-	-	-	-	-	-	-	-	-	58	-	12	-	2	-	-	32	-	-	-	-	1	-	-	-	W-1
8/1	41°40'	158°22'	-	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-	3	-	-	-	-	22	2	-	-	-
8/2	42°53'	158°30'	-	-	-	-	-	-	-	-	-	23	-	1	-	2	-	-	6	-	-	-	-	7	-	-	-	P-2 W-1
8/5	46°43'	159°45'	-	-	-	-	-	-	-	-	-	2	-	4	-	3	-	-	10	-	-	-	-	6	-	-	-	SW-7 FS-7 P-4
8/6	49°41'	159°45'	-	-	-	-	-	-	-	-	-	4	-	36	-	-	-	-	54	-	-	-	-	2	2	-	-	W-4 P-4
8/7	52°49'	159°56'	4	-	1	3	-	3	-	-	3	4	-	133	-	4	-	-	17	-	-	49	15	-	-	-	Und-2	UW-2 P-4
8/8	52°17'	161°28'	-	-	-	-	-	-	-	-	-	-	-	75	-	-	-	-	14	4	-	-	-	-	-	-	-	FS-1 P-15
8/9	50°13'	165°00'	-	-	-	-	-	-	-	-	-	-	-	51	-	-	-	-	33	-	-	7	-	-	-	-	-	P-2
8/10	49°49'	170°10'	1	-	1	-	-	-	-	-	1	7	-	71	-	7	-	-	33	4	4	-	-	-	-	-	-	KW-3 W-2 P-8
8/12	46°54'	174°59'	-	-	-	-	-	-	-	-	-	12	5	11	4	-	-	-	10	-	-	-	-	-	-	-	-	-
8/13	45°36'	174°56'	-	-	-	-	-	-	-	-	-	10	-	36	-	-	-	-	11	-	-	-	-	-	-	-	-	-
8/14	45°08'	174°44'	-	-	-	-	-	-	-	-	-	2	-	21	-	-	-	-	3	-	-	-	-	-	-	-	-	FS-1
8/15	44°16'	174°42'	-	-	-	-	-	-	-	-	-	7	3	84	-	-	-	-	5	-	-	-	4	-	-	-	-	W-1
8/16	43°22'	174°43'	-	-	-	-	-	-	-	-	-	3	1	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/17	42°57'	174°57'	-	-	-	-	-	-	-	-	-	6	2	12	-	-	-	-	1	-	-	-	-	-	-	-	-	-
8/22	41°33'	175°02'	-	-	-	-	-	-	-	-	-	48	1	4	-	-	-	-	26	-	-	-	-	-	-	-	-	SK-1
8/23	41°04'	175°10'	-	-	-	-	-	-	-	-	-	22	9	-	-	-	-	-	2	-	-	-	-	-	1	-	-	-
8/24	38°14'	175°00'	1	-	1	-	-	-	-	-	1	13	6	94	-	-	-	1	16	-	-	-	-	-	-	-	-	-
8/25	39°28'	170°58'	-	-	-	-	-	-	-	-	-	27	-	13	-	-	-	-	17	-	-	-	-	-	-	-	-	-
8/28	41°42'	170°32'	-	-	-	-	-	-	-	-	-	33	6	14	-	3	-	-	32	-	-	-	-	2	-	-	-	SW-1
8/31	44°58'	168°42'	-	-	-	-	-	-	-	-	-	15	-	6	-	1	-	-	6	-	-	-	-	1	-	-	-	-
9/1	46°16'	165°29'	-	-	-	-	-	-	-	-	-	12	-	14	-	-	-	-	7	-	-	-	-	-	-	-	-	P-5
9/3	44°41'	165°05'	-	-	-	-	-	-	-	-	-	21	1	5	-	-	-	-	6	-	-	-	-	-	-	-	-	-
9/4	41°58'	163°46'	-	-	-	-	-	-	-	-	-	8	5	3	-	1	-	-	25	-	-	-	-	-	-	-	-	-
9/5	37°46'	163°09'	-	-	-	-	-	-	-	-	-	6	-	3	-	-	-	-	9	-	-	-	-	-	-	1	-	-
9/6	34°13'	161°59'	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
9/7	30°24'	160°37'	-	-	-	-	-	-	-	-	-	2	-	3	-	-	-	1	1	-	-	-	-	-	-	-	-	-
9/8	26°31'	159°32'	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	1	-	-	-	-	-	-	-	-	-	-
9/9	22°40'	158°30'	1	-	-	1	1	-	-	1	1	-	-	37	1	11	-	3	-	-	-	-	2	-	-	-	-	-

Table 12.--Zooplankton station data and volumes, Hugh M. Smith cruise 46

Station and Tow	Date, 1958	Time (GCT)	Latitude N.	Longitude W.	Depth (m.)	Volume (cc./1000 m.^{3})
2-A	7/22	0823-0845	-	-	75	-
2-B	7/22	0849-0916	-	-	57	-
4-1	7/23	0723-0756	23°56'	158°28'	142	39
4-2	7/23	0801-0820	23°56'	158°28'	Surface	19
7-1	7/24	0750-0823	27°08'	158°38'	130	56
7-2	7/24	0828-0850	27°08'	158°38'	Surface	39
10-1	7/25	0819-0855	30°36'	158°56'	137	28
10-2	7/25	0901-0922	30°36'	158°56'	Surface	27
13-1	7/26	0804-0836	34°03'	158°54'	144	60
16-1	7/27	0845-0919	37°25'	159°09'	141	45
16-2	7/27	0920-0940	37°25'	159°09'	Surface	37
19-1	7/28	0858-0938	39°41'	159°24'	140	52
19-2	7/28	0940-1000	39°41'	159°24'	Surface	53
22-1	7/29	0845-0915	40°49'	159°38'	150	35
22-2	7/29	0920-0940	40°49'	159°38'	Surface	19
26-1	7/30	0841-0920	41°20'	159°56'	109	47
26-2	7/30	0922-0937	41°20'	159°56'	Surface	28
29-1	7/31	0751-0825	41°46'	159°24'	142	62
29-2	7/31	0821-0847	41°46'	159°24'	Surface	23
33-1	8/1	0740-0812	41°09'	158°24'	123	47
33-2	8/1	0813-0837	41°09'	158°24'	Surface	36
37-1	8/2	0745-0815	42°19'	158°22'	140	68
37-2	8/2	0818-0838	42°19'	158°22'	Surface	20
40-1	8/3	0752-0824	43°10'	158°47'	140	26
40-2	8/3	0836-0856	43°10'	158°47'	Surface	22
43-1	8/5	0820-0853	45°02'	159°23'	143	76
43-2	8/5	0855-0915	45°02'	159°23'	Surface	124
46-1	8/6	1030-1104	48°06'	159°42'	141	96
46-2	8/6	1106-1126	48°06'	159°42'	Surface	158
48-1	8/7	0828-0905	50°56'	159°49'	142	177
48-2	8/7	0907-1030	50°56'	159°49'	Surface	226
50-1	8/8	0743-0809	54°00'	159°56'	140	171
50-2	8/8	0812-0833	54°00'	159°56'	Surface	333
53-1	8/12	1213-1240	48°03'	174°45'	140	216
53-2	8/12	1244-1304	48°03'	174°45'	Surface	-
56-1	8/13	0839-0917	46°12'	174°56'	137	meter malfunctioned
56-2	8/13	0920-0940	46°12'	174°56'	Surface	285
60-1	8/14	0824-0847	45°11'	174°54'	114	78
63-1	8/16	0626-0646	43°29'	174°48'	145	86
63-2	8/16	0750-0815	43°29'	174°48'	Surface	123
64-1	8/17	0535-0550	43°22'	174°43'	142	52
67-1	8/18	0600-0636	42°48'	175°08'	142	42
68-1	8/19	0620-0640	42°46'	175°08'	Surface	21
69-1	8/20	0808-0828	41°35'	175°08'	143	meter malfunctioned
69-2	8/20	0843-0905	41°35'	175°08'	Surface	139
71-1	8/22	2320-2330	41°33'	175°02'	Surface	not determined
75-1	8/23	0539-0617	41°35'	175°01'	137	45
79-1	8/24	0526-0550	40°29'	175°11'	143	17
79-2	8/24	0552-0617	40°29'	175°11'	Surface	17
85-1	8/26	0908-0939	39°50'	170°52'	112	55
85-2	8/26	0942-1003	39°50'	170°52'	Surface	43
88-1	8/27	0525-0557	40°15'	170°16'	141	33
88-2	8/27	0859-0914	40°15'	170°16'	Surface	20
90-1	8/29	0835-0848	42°21'	170°12'	140	145
90-2	8/29	0852-0910	42°21'	170°12'	Surface	937
91-1	8/30	0936-1012	42°50'	169°57'	156	77
91-2	8/30	1014-1035	42°50'	169°57'	Surface	240

Table 12.--Zooplankton station data and volumes, Hugh M. Smith cruise 46 (cont'd)

Station and Tow	Date, 1958	Time (GCT)	Latitude N.	Longitude W.	Depth (m.)	Volume (cc./1000 m.^{3})
94-1	8/31	0509-0539	43°57'	169°30'	173	43
94-2	8/31	0541-0605	43°57'	169°30'	Surface	14
96-1	9/1	0618-0647	45°45'	168°47'	141	112
96-2	9/1	0723-0744	45°45'	168°47'	Surface	36
98-1	9/2	0459-0521	46°34'	168°44'	140	51

Table 13.--Station curves and observed oceanographic data, Hugh M. Smith cruise 46

Notes on Oceanographic Station Curves

Thermosteric anomaly (oblique lines) are in centiliters per ton (Montgomery 1954). Where temperatures of paired thermometers differed by more than 0.05°C. below 300 m. or more than 0.10°C. above 300 m., both values are plotted and designated by the symbol ∴△ . The other variables are plotted for each of the temperature values. When the station curve is not drawn through a plotted value, it is considered a gross error and not used.

Explanatory code for station curves:

△ Reversing thermometer temperatures °C.
• BT temperature °C.
⊡ Salinity °/oo.
▽ Dissolved oxygen ml. /L.

Notes on Observed Oceanographic Data

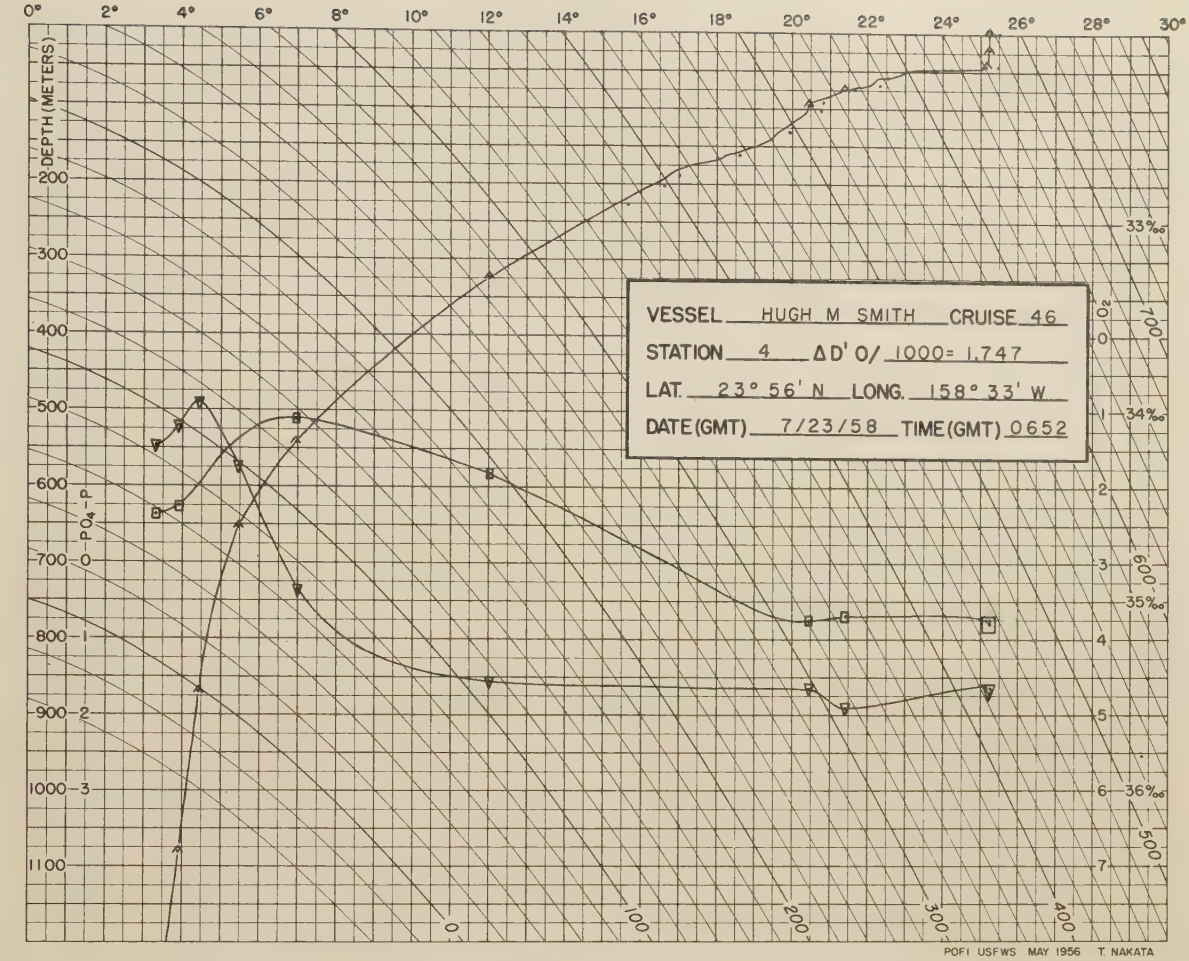
Where more than one cast was made on a station, they are separated by a horizontal line. The cast number is indicated by a Roman numeral in the margin.

Where the corrected readings of the paired protected thermometers differed by more than 0.05°C. below 300 m. or more than 0.10°C. above 300 m., both temperature values are tabulated and the depth and salinity are repeated. Delta-t calculated using each temperature value is carried.

Explanatory code for tabulated data:

NG - The value or line is in error and is discarded.
Q - The value seems questionable but was used in construction of the station curve.
P - The value is questionable and while carried was not used in drawing the station curve.
NS - No sample.
(2) - Indicates H_2S precipitate in salinity sample.

NOTE: In calculating the depths of reversal from the readings of unprotected reversing thermometers, an error was introduced into the formula $D = \frac{Tu - Tw}{Q \rho_m}$. Instead of the factor $1/(Q x \rho_m)$, values for $(1/Q) x \rho_m$ were used. Therefore, multiplication of depth in table 13 by 0.942 will give the proper value for the depth of each observation.

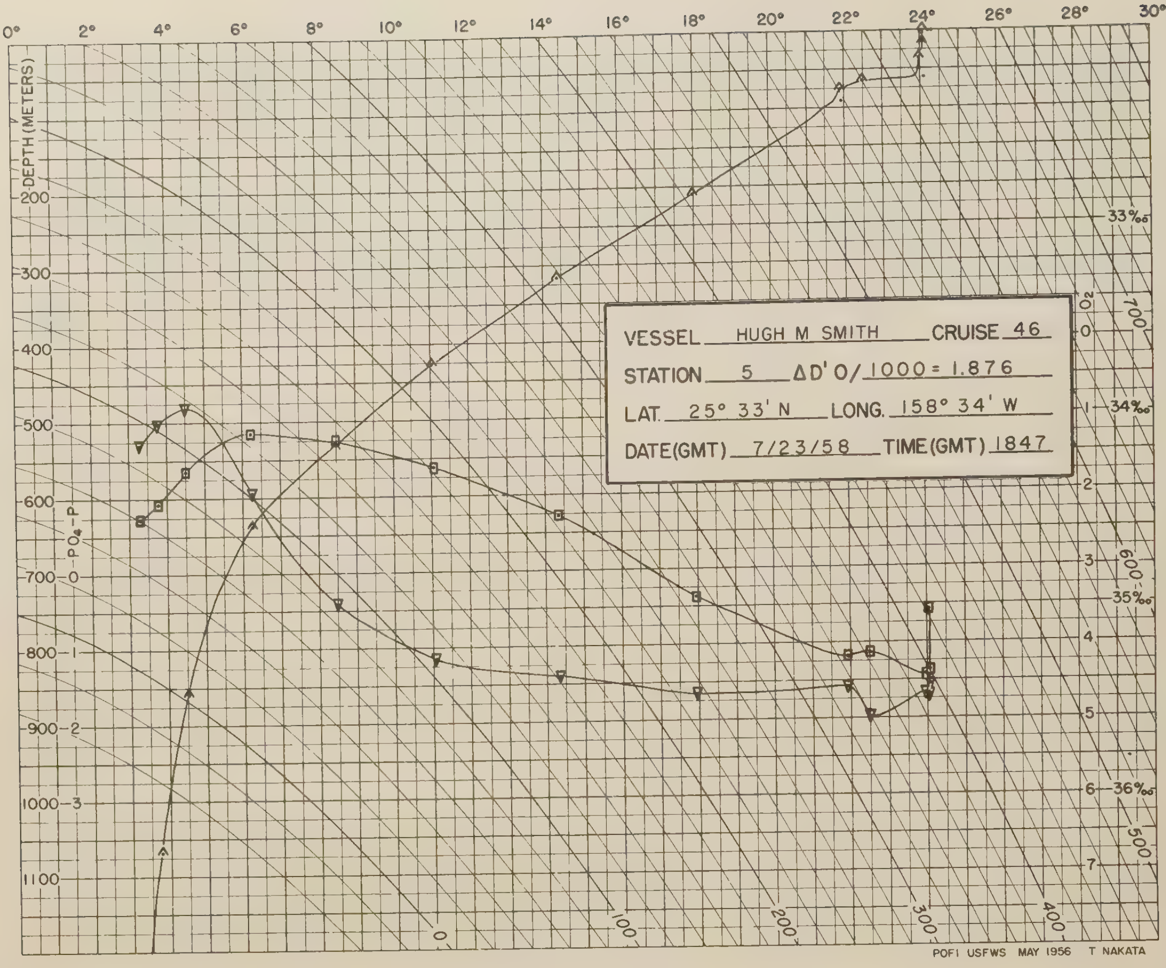


VESSEL HUGH M SMITH CRUISE 46
STATION 4 ΔD' 0/1000= 1.747
LAT. 23° 56' N LONG. 158° 33' W
DATE (GMT) 7/23/58 TIME (GMT) 0652

Weather: 02, cloud coverage: not recorded. Wind: 060°, 18 kts. Sea: 3-5 ft. Wire angle: < 03°. BT slide: 15. Dry bulb: 76.2°F. Wet bulb: 70.8°F. Barometric pressure: 1019 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	25.23	35.10	452.2	4.66	0.58
21	25.22	35.12	450.6	4.72	0.43
42	25.14	35.10	449.8	4.64	0.47
74	21.40	35.08	347.8	4.91	0.49
96	20.44	35.10	321.5	4.66	0.58
218	NG	34.64	-	4.38	1.31
324	12.04	34.33	193.8	4.57	1.23
436	NG	35.17	-	4.31	1.76
542	6.95	34.04	135.8	3.34	2.38
653	5.45	34.54 P	80.3	1.73	3.19
870	4.43	34.94 P	39.2	0.89	3.69
1081	3.90	34.50	66.9	1.20	3.46
1297	3.33	34.55	57.9	1.47	3.77* 3.19

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.



VESSEL HUGH M SMITH CRUISE 46
STATION 5 ΔD' 0/1000 = 1.876
LAT. 25° 33' N LONG. 158° 34' W
DATE(GMT) 7/23/58 TIME(GMT) 1847

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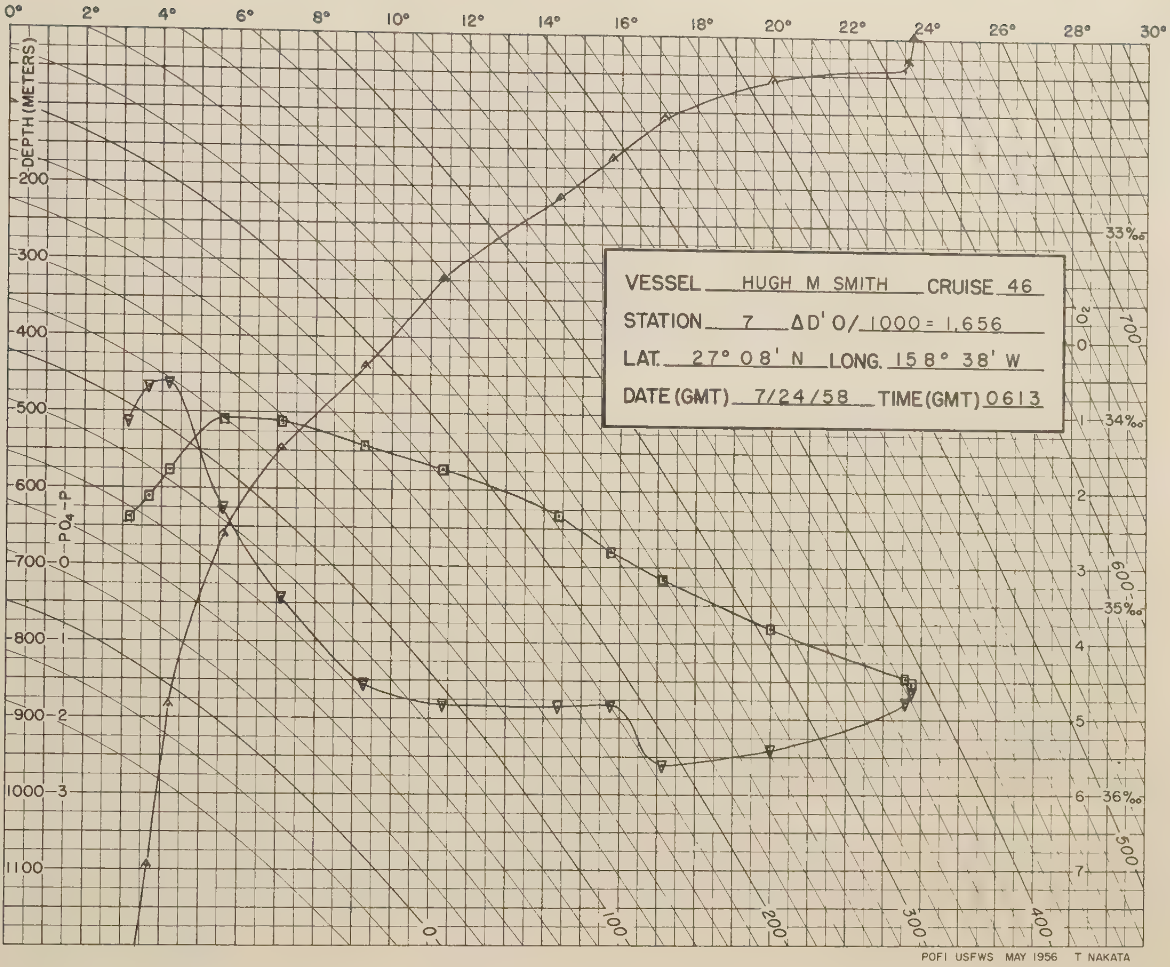
Weather: 03, cloud coverage: 9. Wind: 050°, 10 kts. Sea: 1-3 ft. Wire angle: 00°. BT slide: 19. Dry bulb: 76.8°F. Wet bulb: 71.9°F. Barometric pressure: 1020 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O_2, ml./L.	PO_4-P, μg at./L.
0	24.06	35.35	400.9	4.55	0.30
15	24.04	35.03	423.4	4.70	0.25
36	23.97	35.37	396.7	4.99	0.35
66	22.48	35.25	364.2	4.67	0.48
76	21.92	35.27	347.7	4.59	0.35
210	17.96	34.95	271.7	4.66	0.63
316	14.37	34.51	225.4	1.02	2.29
427	11.05	34.25	182.4	0.81	2.92
532	8.46	34.11	151.7	1.94	2.08
638	6.24	34.06	125.5	3.41	1.24
858	4.50	34.26	91.0	4.40	0.66
1068	3.76	34.43	70.8	4.16	0.43
1282	3.29	34.51	60.4	1.29	3.71

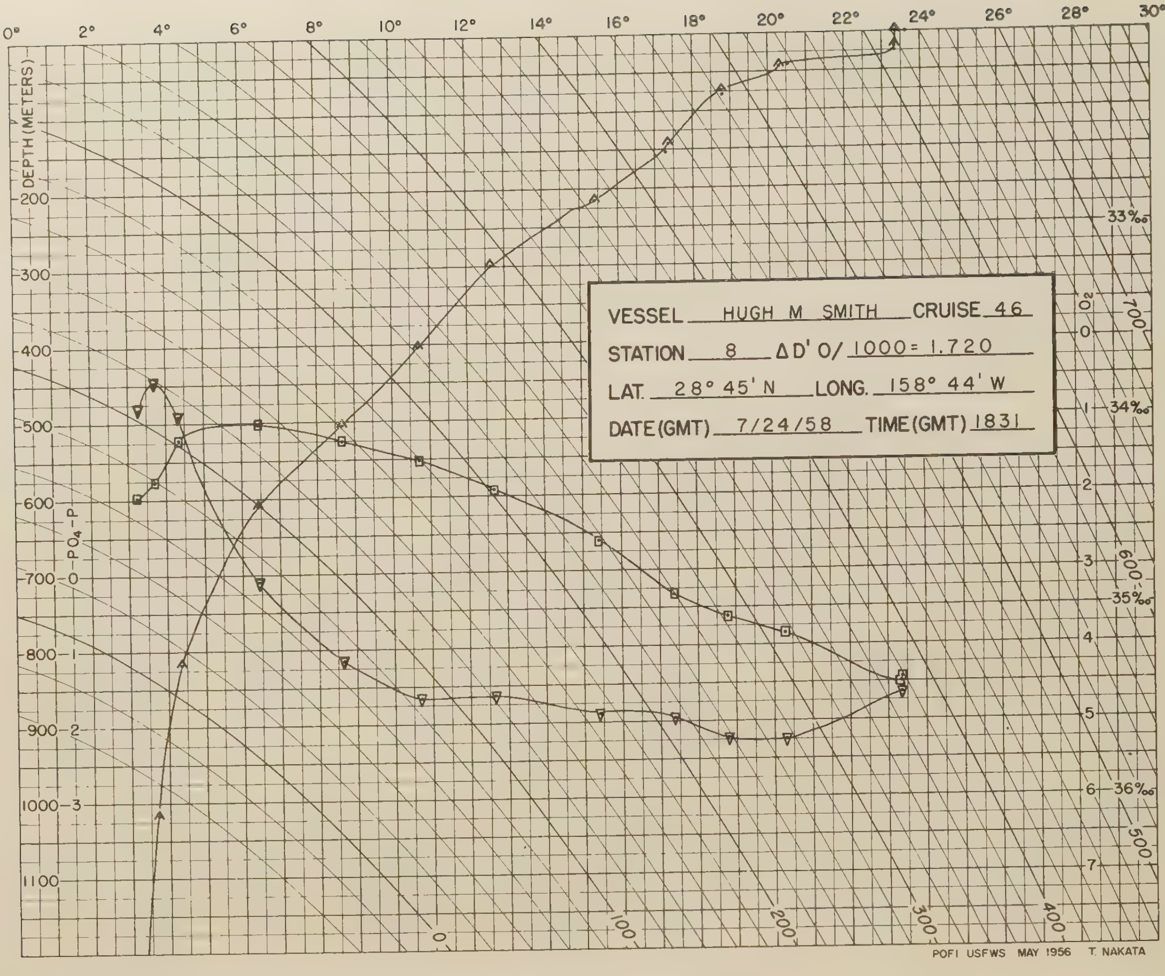


VESSEL HUGH M SMITH CRUISE 46
STATION 7 ΔD' 0/1000 = 1.656
LAT. 27° 08' N LONG. 158° 38' W
DATE (GMT) 7/24/58 TIME (GMT) 0613

Weather: 02, cloud coverage: 2. Wind: 070°, 14 kts. Sea: 3-5 ft. Wire angle: 01°. BT slide: 22. Dry bulb: 75.3°F. Wet bulb: 69.8°F. Barometric pressure: 1020 mbs.

Depth, m.	T, °C.	S, °/oo	δ_t, cl. /ton	O$_2$, ml. /L.	PO$_4$-P, µg at. /L.
0	23.74	35.42	386.7	4.61	0.40
32	23.58	35.39	384.2	4.78	0.20
58	19.98	35.12	308.4	5.42	0.09
110	17.13	34.86	259.2	5.61	0.24
163	15.75	34.72	238.9	4.82	0.38
216	14.38	34.53	224.2	4.84	0.48
324	11.34	34.29	184.6	4.82	0.98
439	9.29	34.17	159.7	4.56	1.51
548	7.10	34.04	137.9	3.42	2.22
662	5.60	34.03	120.3	2.25	2.93
884	4.21	34.30	84.9	0.61	3.59
1097	3.66	34.44	69.1	0.67	3.70
1312	3.16	34.55	56.3	1.12	2.65* 3.35

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.

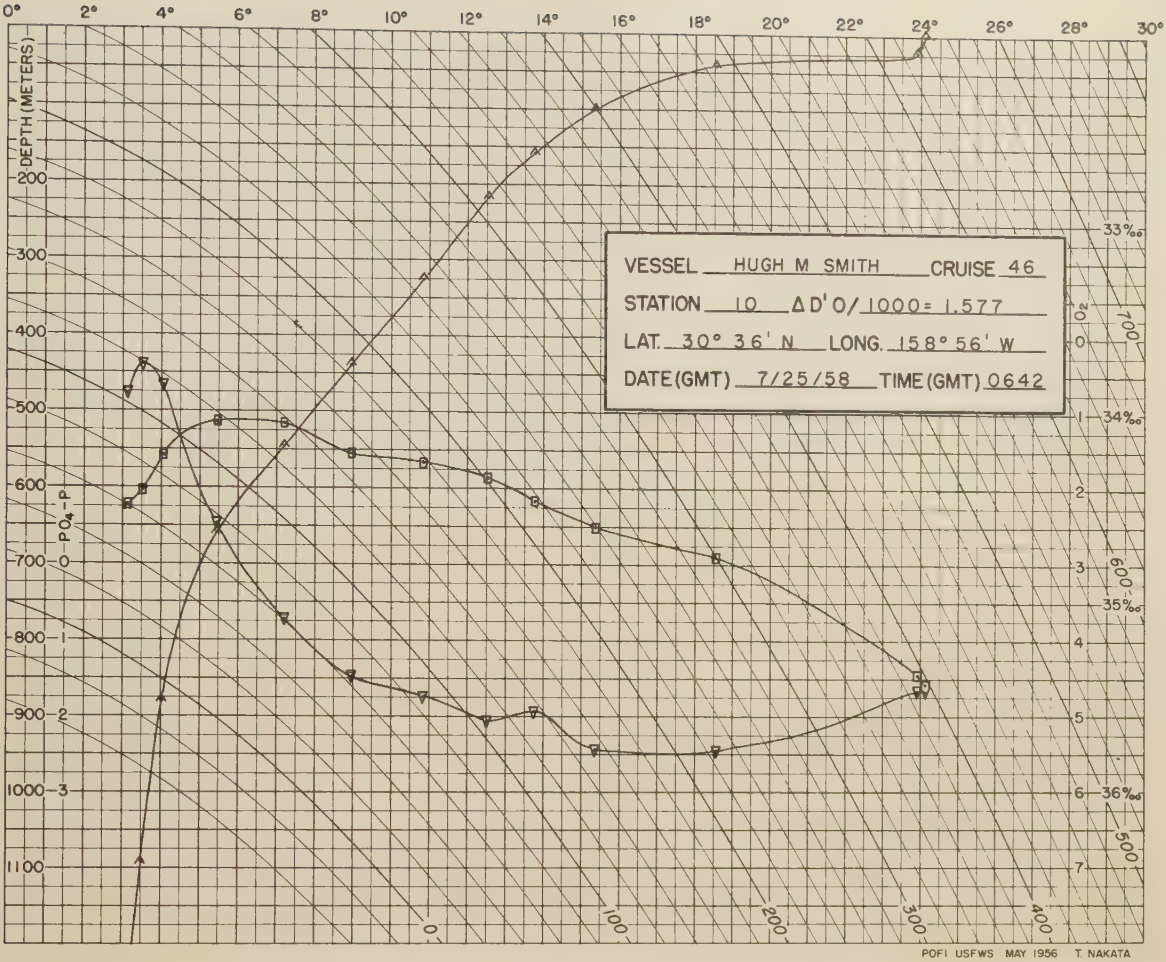


Weather: 02, cloud coverage: 9. Wind: 100°, 10 kts. Sea: 1-3 ft. Wire angle: 20°. BT slide: 27. Dry bulb: 75.9°F. Wet bulb: 70.0°F. Barometric pressure: 1021 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O_2, ml./L.	PO_4-P, µg at./L.
0	23.36	35.38	378.8	4.66	0.30
20	23.34	35.40	376.9	4.66	0.12
44	20.30	35.14	315.1	5.24	0.12
73	18.77	35.05	283.8	5.22	Trace
142	17.36	34.93	259.4	4.96	0.17
215	15.41	34.64	237.4	4.87	0.35
299	12.65	34.37	202.1	4.63	0.62
404	10.68	34.21	179.0	4.66	0.70
504	8.65	34.10	155.3	4.14	0.96
610	6.43	34.01	131.7	3.09	2.05
817	4.36	34.09	102.3	0.91	3.10
1018	3.68	34.31	79.0	0.48	3.45
1223	3.26	34.39 1/	69.2	0.81	3.47*
					3.11

1/ Sample bottle only 3/4 full.

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.



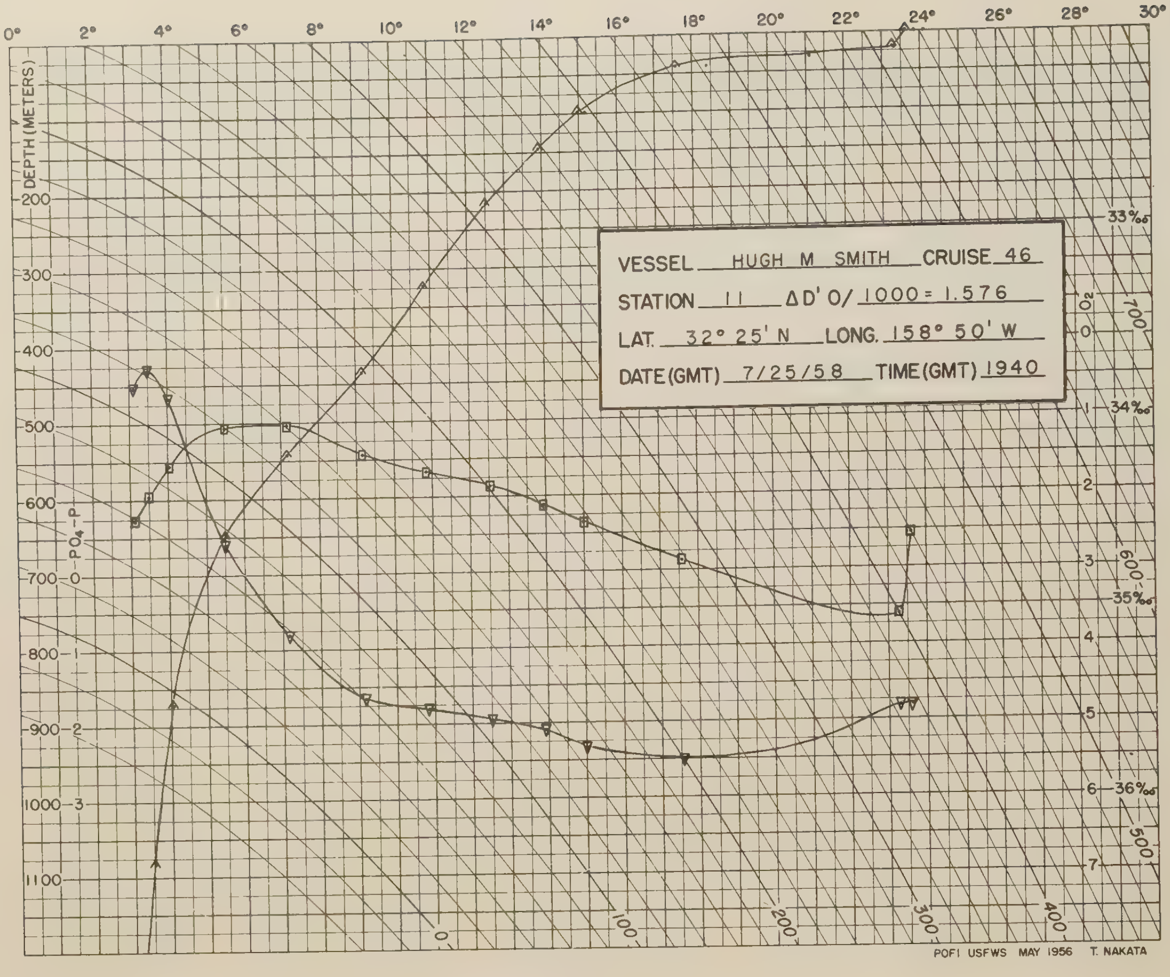
VESSEL HUGH M SMITH CRUISE 46
STATION 10 ΔD'0/1000= 1.577
LAT. 30° 36' N LONG. 158° 56' W
DATE (GMT) 7/25/58 TIME (GMT) 0642

POFI USFWS MAY 1956 T. NAKATA

Weather: 02, cloud coverage: 2. Wind: 120°, 10 kts. Sea: 1-3 ft. Wire angle: 04°. BT slide: 31. Dry bulb: 75.1°F. Wet bulb: 68.5°F. Barometric pressure: 1019 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	24.10	35.43	396.1	4.68	0.66
21	23.88	35.38	393.4	4.68	0.11
41	18.56	34.76	299.8	5.46	0.13
100	15.36	34.60 2/	239.4	5.43	0.17
159	13.75	34.46	216.8	4.94	0.34
217	12.54	34.34	202.5	5.06	0.45
326	10.85	34.26 2/	178.1	4.74	0.80
439	8.96	34.22 2/	150.8	4.49	1.20
546	7.20	34.06 2/	137.7	3.72	1.47
659	5.43	34.05 2/	116.8	2.47	2.48
879	4.02	34.23 2/	88.4	0.67	2.68
1091	3.52	34.41	70.1	0.39	3.30
1303	3.14	34.49	60.6	0.77	3.28

2/ Indicates H_2S precipitate in salinity sample.



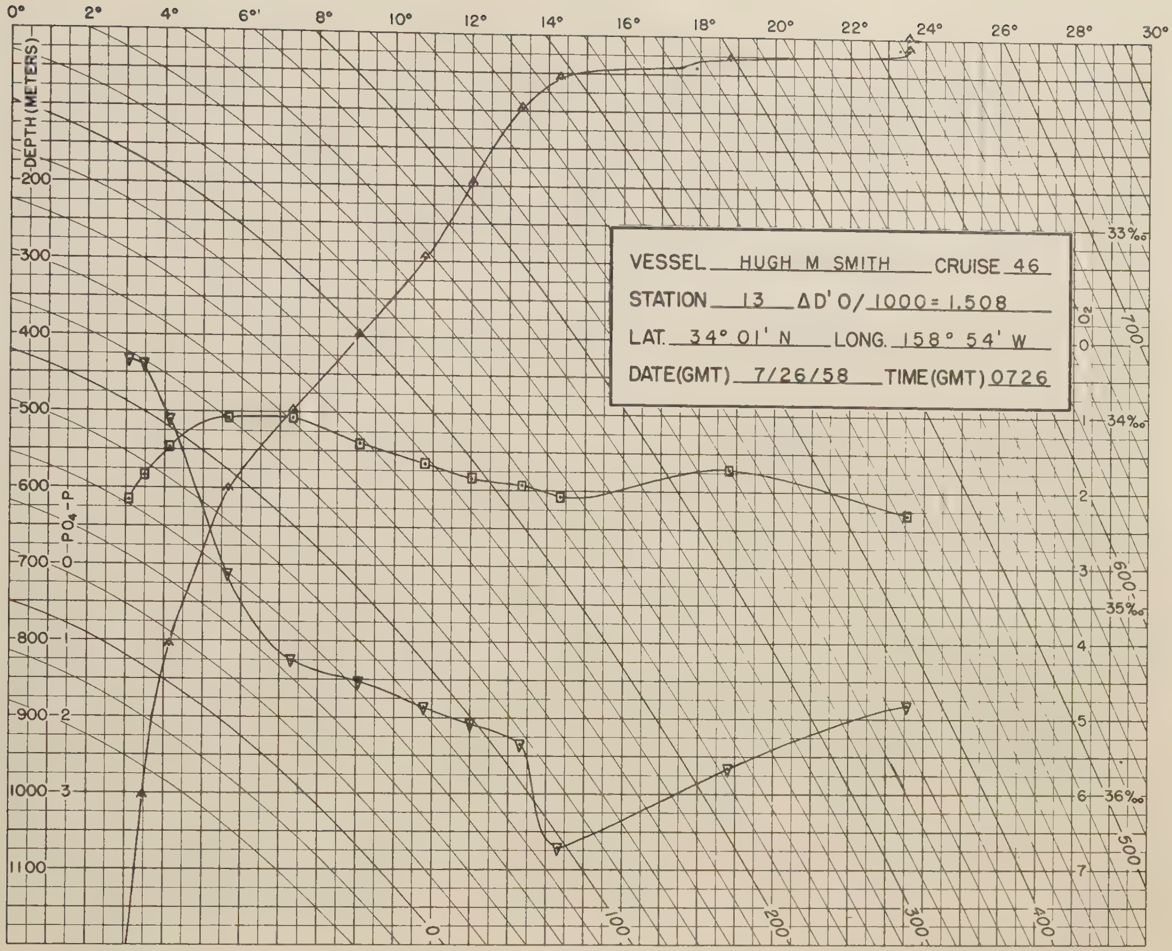
VESSEL HUGH M SMITH CRUISE 46
STATION 11 ΔD' 0/1000 = 1.576
LAT. 32° 25' N LONG. 158° 50' W
DATE (GMT) 7/25/58 TIME (GMT) 1940

Weather 02, cloud coverage: 4. Wind: 190°, 13 kts. Sea: 1-3 ft. Wire angle: < 03°. BT slide: 35. Dry bulb: 75.0°F. Wet bulb: 69.1°F. Barometric pressure: 1018 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	23.60	34.62	440.3	4.81	0.12
20	23.26	35.05 2/	399.9	4.82	0.32
41	17.57	34.75 2/	277.2	5.49	0.26
99	14.98	34.54 2/	235.8	5.32	0.12
146	13.92	34.45	220.9	5.10	0.37
215	12.52	34.34 2/	201.8	4.96	0.64
322	10.84	34.27 2/	177.2	4.80	1.00
435	9.16	34.17	157.6	4.65	1.24
542	7.16	34.01 2/	140.8	3.80	1.40
648	5.50	34.02	119.9	2.61	2.42
871	4.02	34.22 2/	89.1	0.67	3.40
1082	3.48	34.38	72.0	0.29	2.82
1294	3.10	34.51	58.7	0.52	3.48*
					3.00

2/ Indicates H_2S precipitate in salinity sample.

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.



VESSEL HUGH M SMITH CRUISE 46
STATION 13 ΔD' 0/1000 = 1.508
LAT. 34° 01' N LONG. 158° 54' W
DATE (GMT) 7/26/58 TIME (GMT) 0726

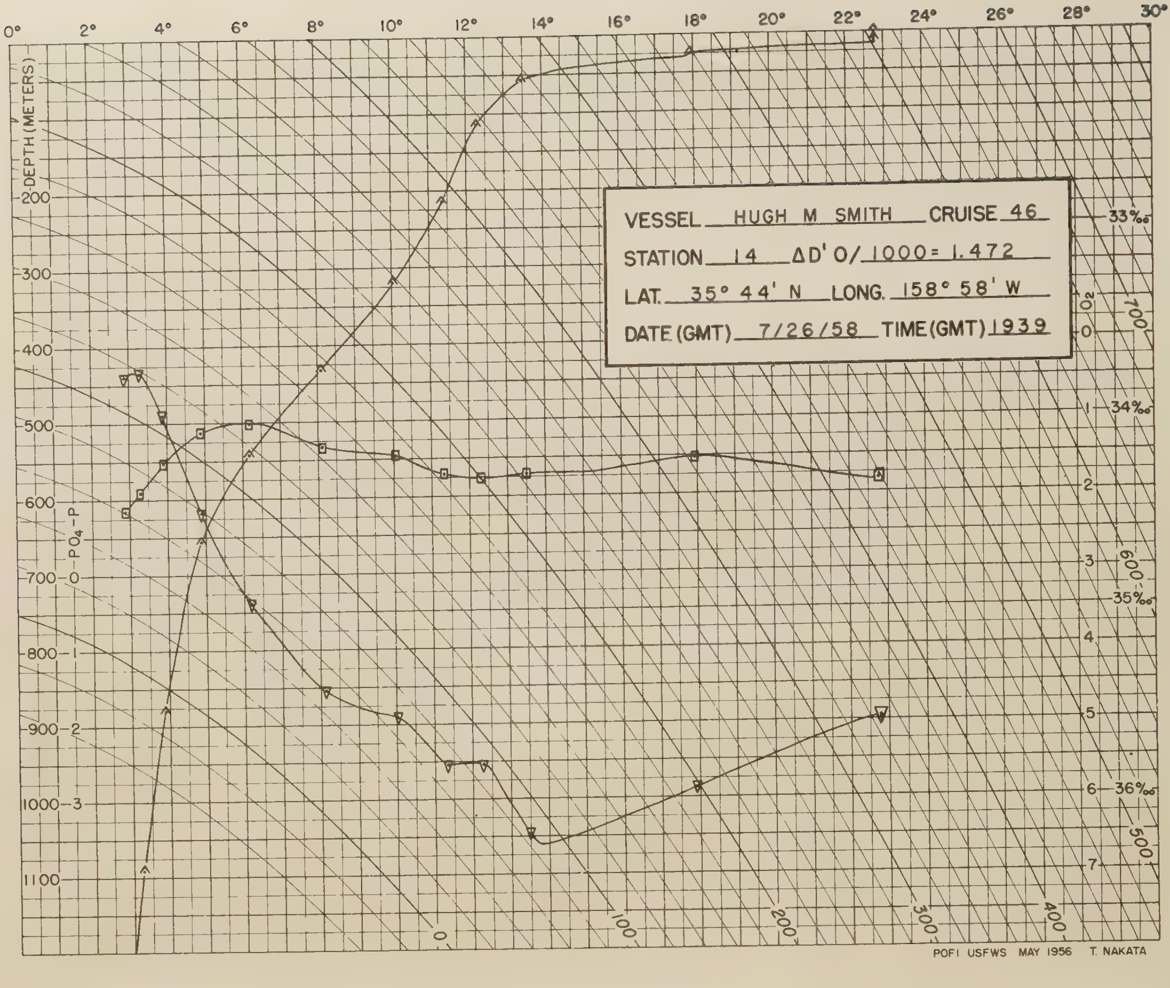
POFI USFWS MAY 1956 T NAKATA

Weather: 03, cloud coverage: not recorded. Wind: 180°, 20 kts. Sea: 3-5 ft. Wire angle: 21°. BT slide: 39. Dry bulb: 75.2°F. Wet bulb: 71.2°F. Barometric pressure: 1016 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	23.56	34.52	446.4	4.83	0.32
15	23.55	34.52	446.2	5.70	0.20
29	18.80	34.28	340.5	5.66	Trace
57	14.32	34.43	230.2	6.71	0.42
96	13.32	34.37	215.0	5.34	0.59
197	12.00	34.34	192.3	5.08	0.59
295	10.80	34.26	177.3	4.87	0.83
398	9.06	34.16 2/	156.8	4.53	0.83
498	7.32	34.03 2/	141.6	4.24	1.32
602	5.65	34.03 2/	120.8	3.13	1.82
806	4.14	34.19 2/	92.5	1.11	2.92
1006	3.46	34.33	75.6	0.40	3.09
1210	3.06	34.46 2/	62.2	0.33	3.17* 3.00

2/ Indicates H_2S precipitate in salinity sample.

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.

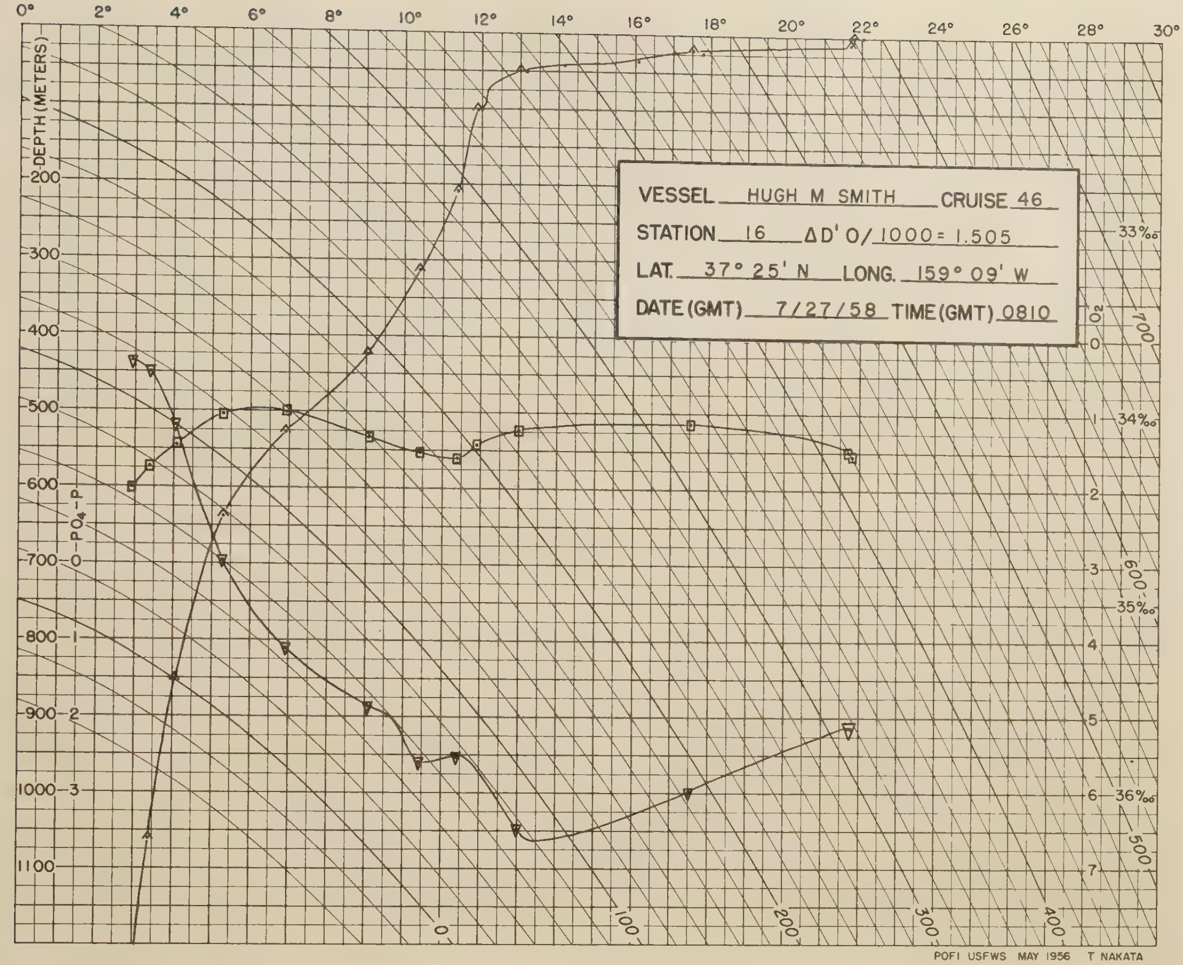


VESSEL HUGH M SMITH CRUISE 46
STATION 14 ΔD' 0/1000= 1.472
LAT. 35° 44' N LONG. 158° 58' W
DATE (GMT) 7/26/58 TIME (GMT) 1939

Weather: 01, cloud coverage: 5. Wind: 020°, 11 kts. Sea: 5-8 ft. Wire angle: 06°. BT slide: 42. Dry bulb: 75.0°F. Wet bulb: 70.4°F. Barometric pressure: 1015 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	22.78	34.32 2/	439.3	4.99	Trace
10	22.77	34.33	438.2	4.96	Trace
26	17.90	34.21	324.2	5.87	Trace
57	13.46	34.28 2/	224.4	6.47	0.32
114	12.28	34.30 2/	200.4	5.53	0.70
214	11.36	34.28	185.7	5.53	0.70
320	10.04	34.18	170.7	4.90	0.70
433	8.10	34.13 2/	144.9	4.54	1.16
543	6.20	34.00 2/	129.5	3.39	2.00
657	4.87	34.05 2/	110.6	2.18	2.20
879	3.87	34.21 2/	88.4	0.90	2.52
1091	3.26	34.36 2/	71.5	0.34	3.25
1303	2.89	34.46 2/	60.8	0.39	3.09

2/ Indicates H_2S precipitate in salinity sample.



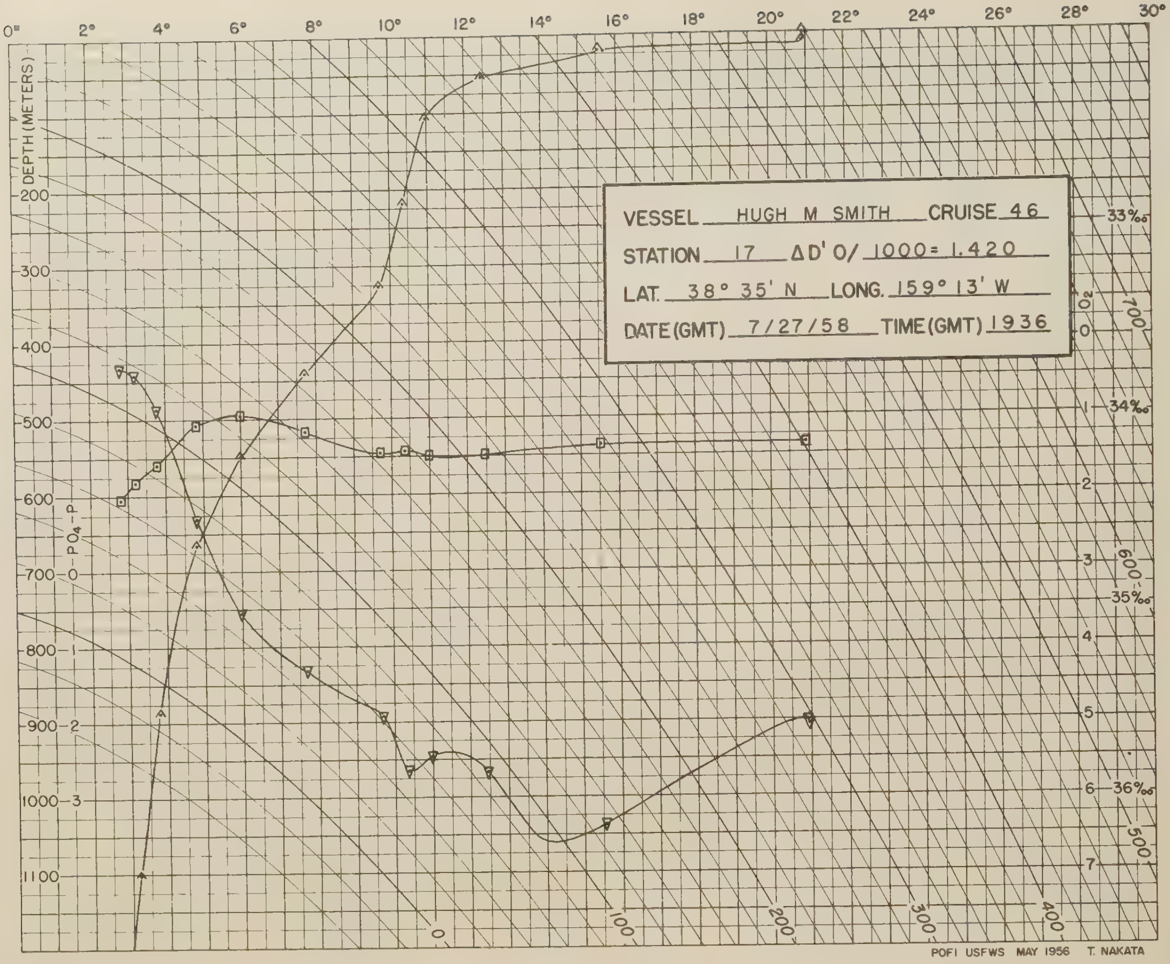
VESSEL HUGH M SMITH CRUISE 46
STATION 16 ΔD' 0/1000 = 1.505
LAT. 37° 25' N LONG. 159° 09' W
DATE (GMT) 7/27/58 TIME (GMT) 0810

POFI USFWS MAY 1956 T NAKATA

Weather: 01, cloud coverage: 7. Wind: 210°, 08 kts. Sea: 1-3 ft. Wire angle: 08°. BT slide: 47. Dry bulb: 72.8°F. Wet bulb: 70.1°F. Barometric pressure: 1017 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	21.80	34.22 2/	420.4	5.13	Trace
10	21.72	34.20 2/	419.8	5.13	Trace
20	17.52	34.05	326.8	5.97	0.20
50	12.98	34.09 2/	229.0	6.47	0.20
101	11.90	34.17	203.2	NS	NS
209	11.39	34.24	189,2	5.52	0.54
313	10.41	34.21	174.7	5.59	0.91
423	9.06	34.13	159.1	4.85	1.16
527	6.92	34.00 2/	138.4	4.10	1.48
638	5.28	34.01 2/	118.1	2.95	1.91
852	4.06	34.18	92.4	1.18	2.82
1060	3.40	34.29	78.1	0.49	3.00
1270	2.94	34.40 2/	65.6	0.34	3.09

2/ Indicates H_2S precipitate in salinity sample.



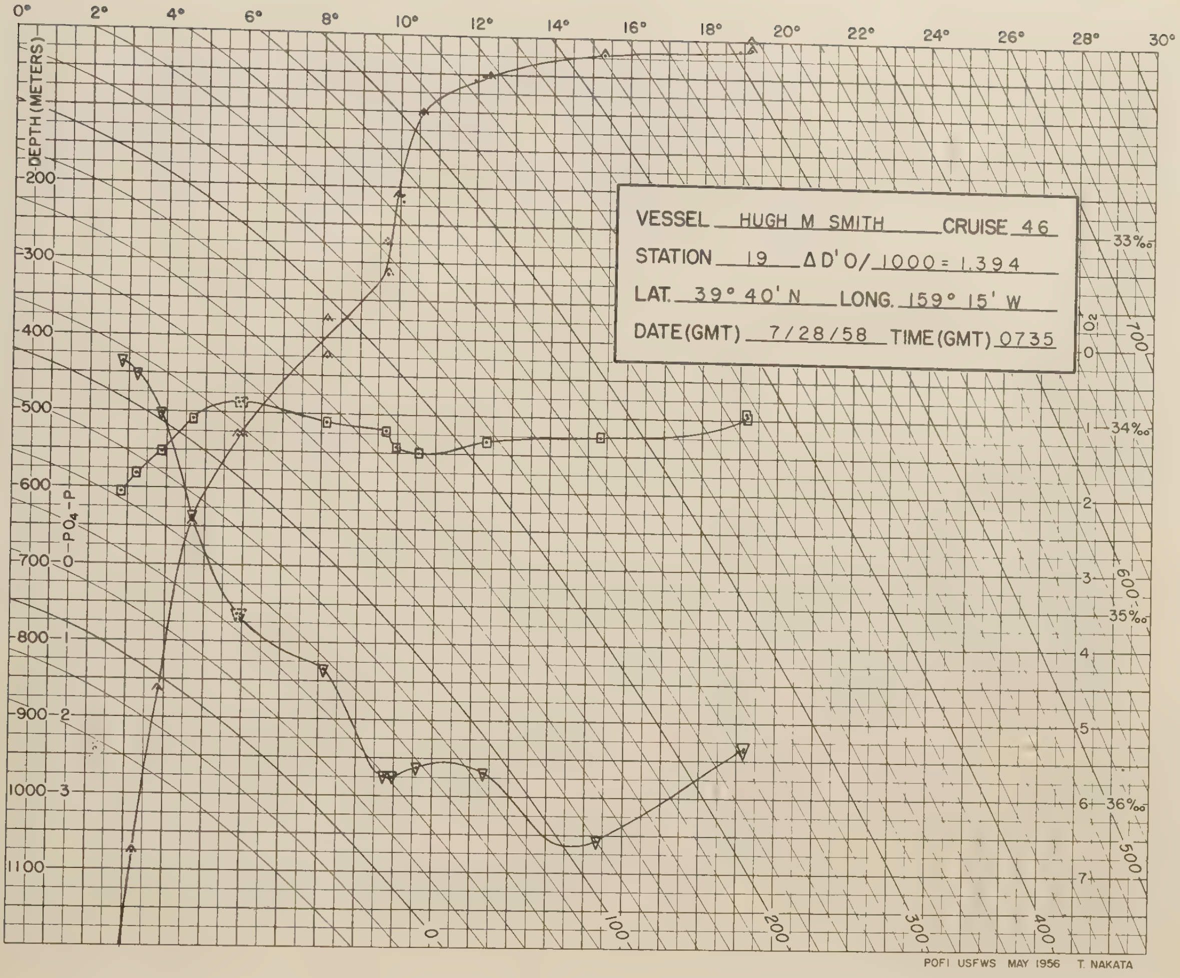
VESSEL HUGH M SMITH CRUISE 46
STATION 17 ΔD' 0/ 1000 = 1.420
LAT. 38° 35' N LONG. 159° 13' W
DATE (GMT) 7/27/58 TIME (GMT) 1936

Weather: 02, cloud coverage: 8. Wind: 250°, 14 kts. Sea: 1-3 ft. Wire angle: 00°. BT slide: 51. Dry bulb: 69.5°F. Wet bulb: 65.9°F. Barometric pressure: 1021 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	20.94	34.14	403.8	5.06	Trace
11	20.93	34.14	403.7	5.01	Trace
21	15.55	34.15 2/	276.2	6.37	Trace
53	12.44	34.20	210.8	5.66	0.26
106	10.98	34.20	184.8	5.46	0.59
219	10.36	34.17	176.7	5.63	0.50
327	9.71	34.18 2/	165.5	4.91	1.00
441	7.69	34.07 2/	143.8	4.31	1.64
550	5.97	33.98	128.2	3.54	1.64
666	4.81	34.03 2/	111.4	2.30	2.20
887	3.76	34.24 2/	85.0	0.85	3.00
1102	3.20	34.33	73.2	0.41	3.00
1317	2.81	34.42	63.2	0.32	2.63* 4.00

2/ Indicates H_2S precipitate in salinity sample.

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.

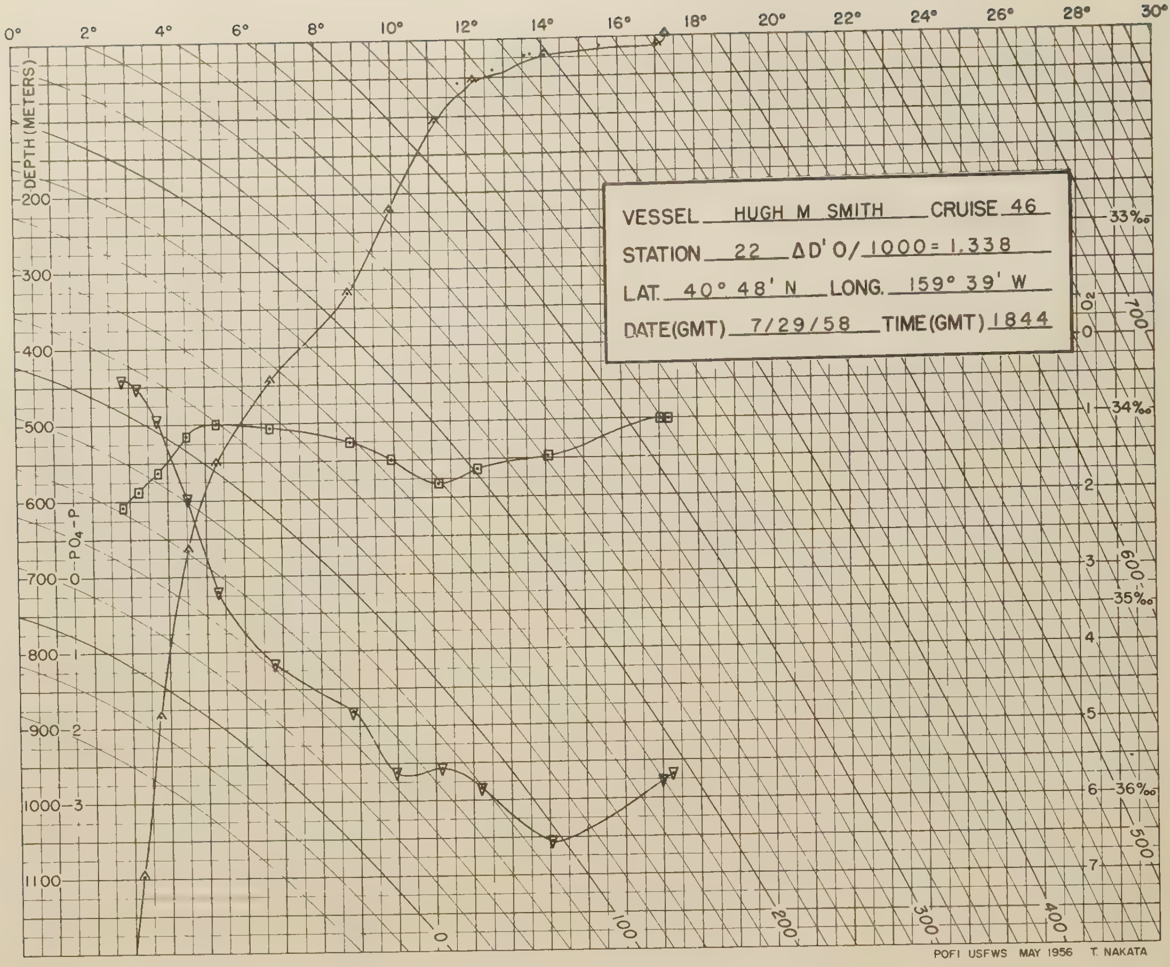


VESSEL HUGH M SMITH CRUISE 46
STATION 19 Δ D' O/ 1000 = 1.394
LAT. 39° 40' N LONG. 159° 15' W
DATE (GMT) 7/28/58 TIME (GMT) 0735

Weather: 02, cloud coverage: not recorded. Wind: 300°, 14 kts. Sea: not recorded. Wire angle: 00°. BT slide: 55. Dry bulb: 67.9°F. Wet bulb: 64.2°F. Barometric pressure: 1022 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	19.18	33.96	373.0	5.36	0.32
11	19.20	33.98 2/	372.0	5.33	0.37
21	15.32	34.10 2/	275.0	6.58	0.37
52	12.33	34.13	213.9	5.69	0.54
103	10.59	34.20 2/	178.3	5.62	0.64
211	9.96	34.17 2/	170.1	5.75	0.70
274	9.72	34.08 Q	173.1	5.74	0.91
315					
376					
424	8.14	34.04	152.2	4.34	1.73
530	5.96 5.85	33.94	131.1 129.8	3.64	2.10
641	4.67	34.03 2/	110.0	2.35	2.92
863	3.85	34.21	88.2	1.01	2.92
1077	3.24	34.32	74.2	0.50	3.00
1292	2.84	34.42	63.4	0.34	3.09

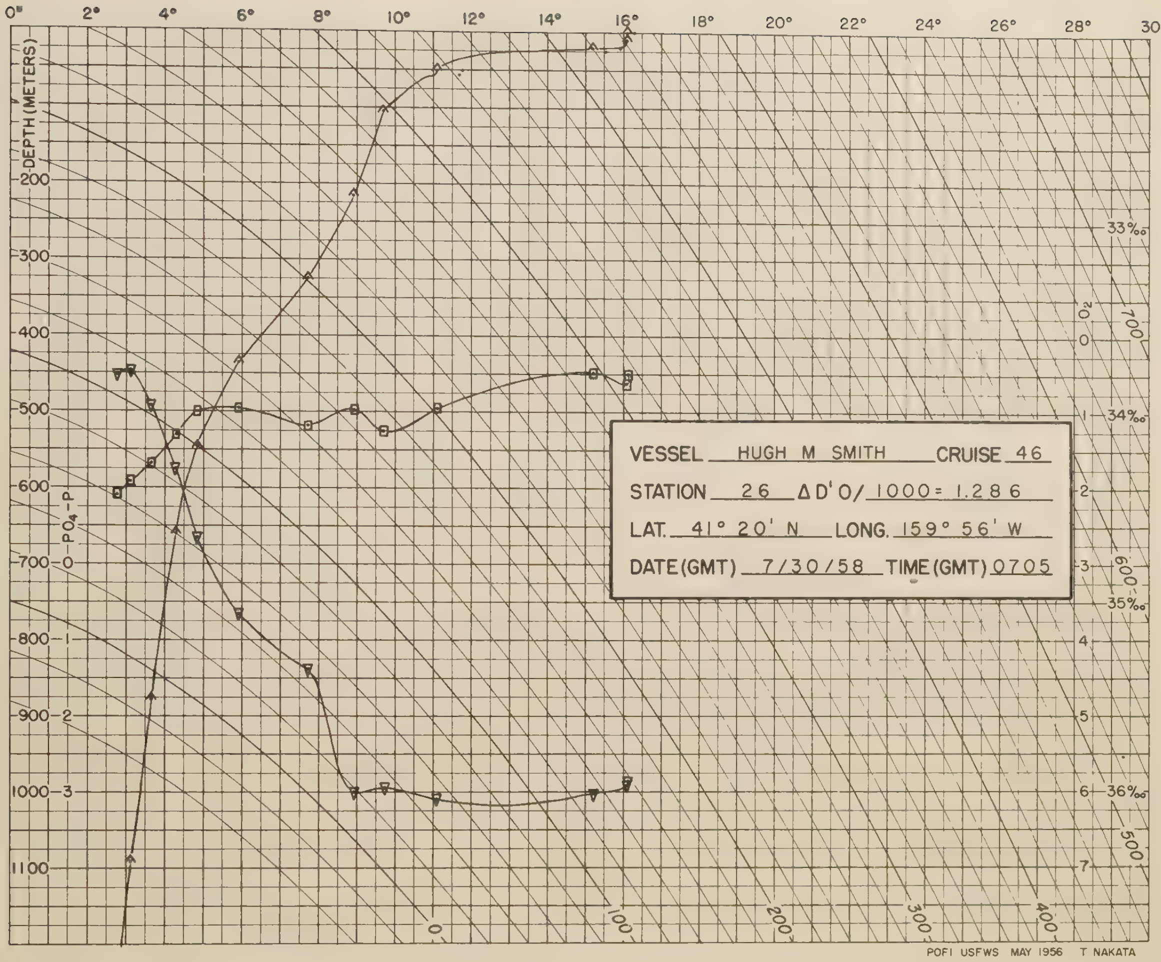
2/ Indicates H_2S precipitate in salinity sample.



Weather: 20, cloud coverage: 8. Wind: 010°, 08 kts. Sea: 1-3 ft. Wire angle: 01°. BT slide: 64. Dry bulb: 62.7°F. Wet bulb: 60.3°F. Barometric pressure: 1027 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O_2, ml./L.	PO_4-P, µg at./L.
0	17.26	34.00	324.5	5.68	0.12
11	17.02	34.00	319.1	5.75	0.20
22	14.06	34.19	242.6	6.55	0.12
54	12.20	34.25	202.5	5.83	0.32
108	11.18	34.32	179.6	5.57	0.54
222	9.94	34.20	167.6	5.61	0.46
330	8.83	34.10	157.8	4.80	0.91
444	6.76	34.02	134.9	4.16	1.73
552	5.29	34.00	118.9	3.19	1.73
665	4.52	34.06	106.2	1.97	2.30
884	3.74	34.25	84.0	0.94	3.00
1097	3.22	34.35	71.9	0.52	3.09
1313	2.80	34.43	62.2	0.40	3.40* 1.91

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.

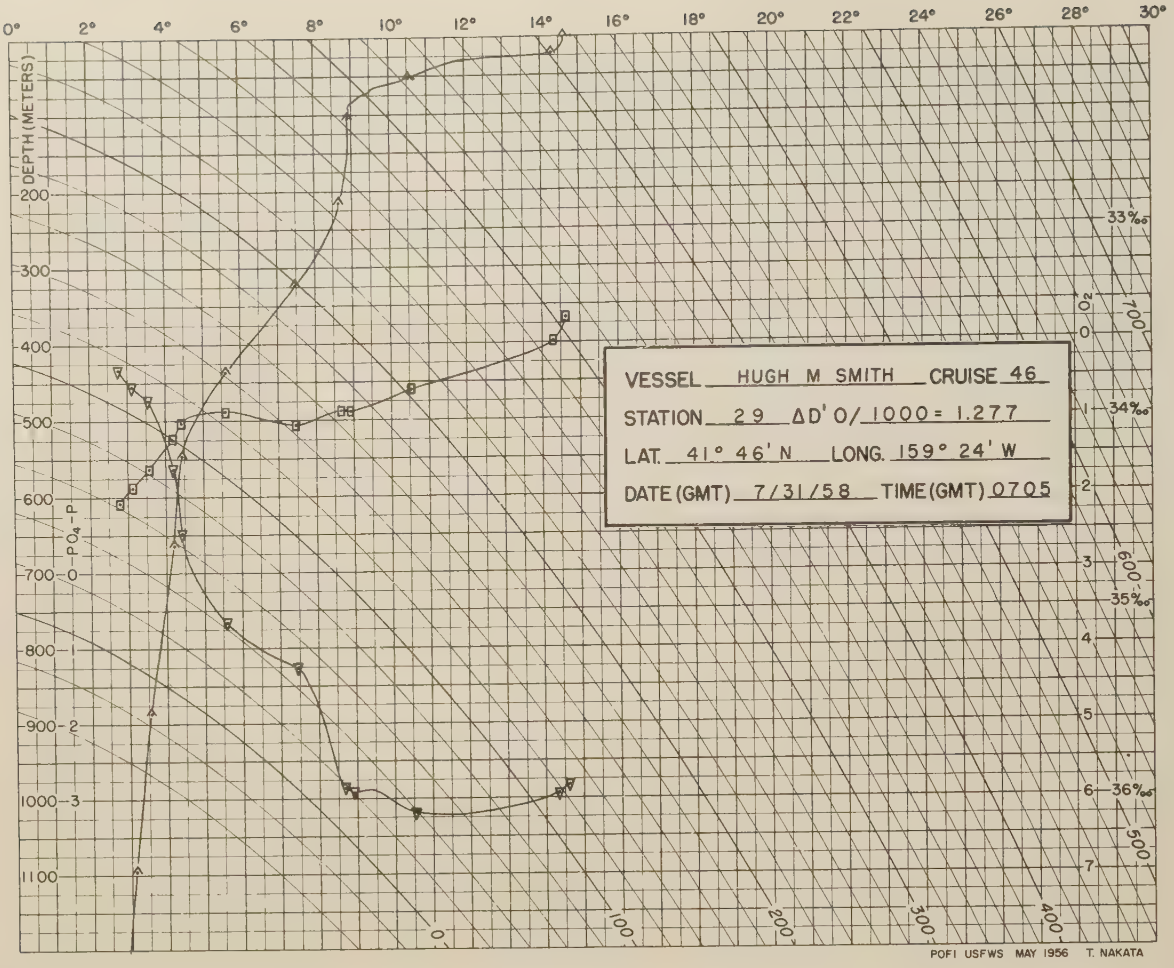


VESSEL HUGH M SMITH CRUISE 46
STATION 26 ΔD'0/1000= 1.286
LAT. 41° 20' N LONG. 159° 56' W
DATE (GMT) 7/30/58 TIME (GMT) 0705

Weather: 03, cloud coverage: 7. Wind: 350°, 08 kts. Sea: 1-3 ft. Wire angle: 00°.
BT slide: 68. Dry bulb: 61.0°F. Wet bulb: 56.0°F. Barometric pressure: 1030 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	16.12	33.80	314.0	5.86	0.42
10	16.08	33.85	309.6	5.91	0.42
21	15.20	33.79 2/	295.0	6.02	0.42
51	11.11	33.98	203.4	6.10	0.54
105	9.73	34.10	171.7	5.94	0.59
216	8.92	33.99	167.3	6.00	0.83
324	7.72	34.07	144.1	4.38	1.48
437	5.90	33.98 2/	127.4	3.64	2.10
547	4.84	34.00	113.9	2.64	2.20
659	4.29	34.12	99.4	1.74	2.30
878	3.64	34.27 2/	81.7	0.92	2.82
1091	3.12	34.37 2/	69.4	0.47	3.00
1303	2.78	34.44 2/	61.4	0.52	2.82

2/ Indicates H_2S precipitate in salinity sample.

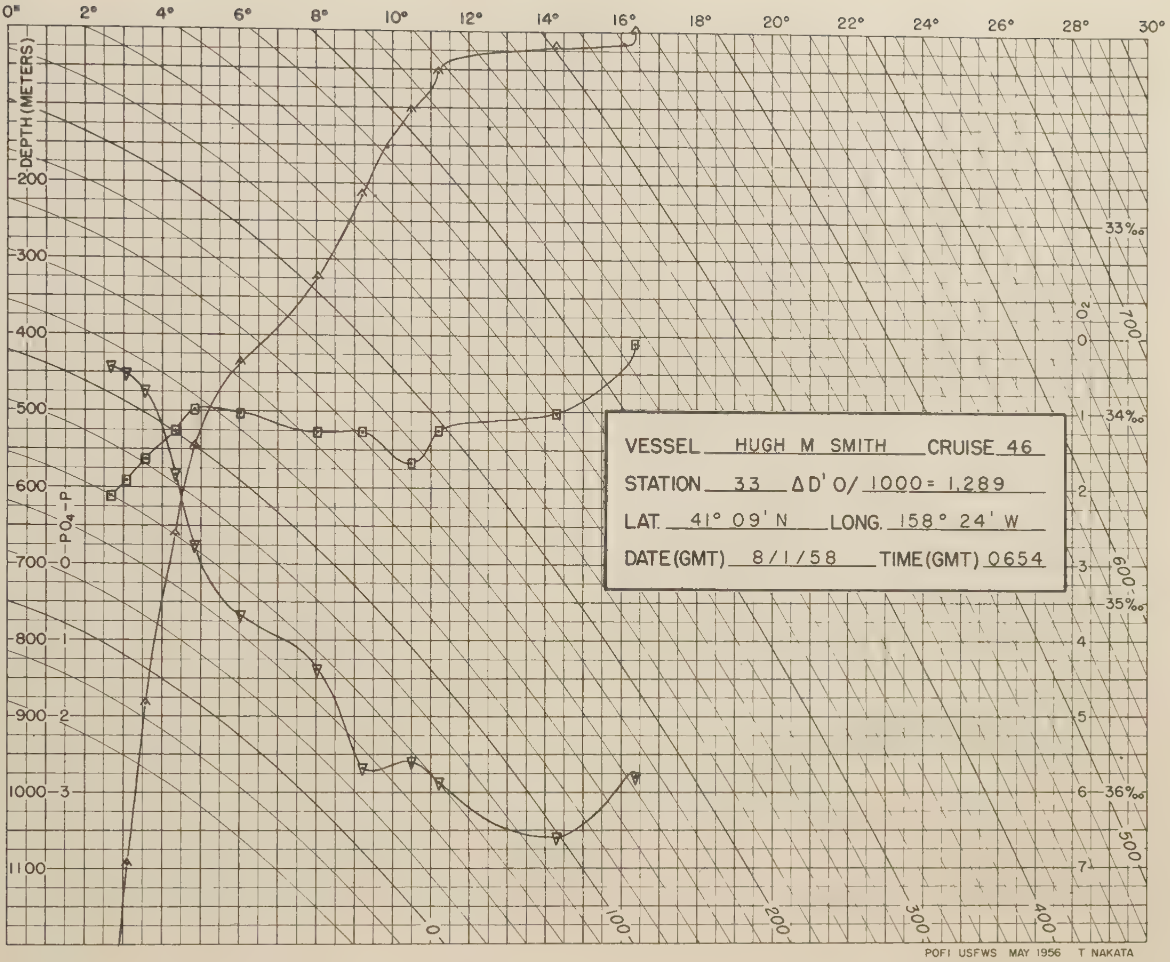


POFI USFWS MAY 1956 T. NAKATA

Weather: 02, cloud coverage: 9. Wind: 310°, 06 kts. Sea: 1-3 ft. Wire angle: 00°. BT slide: 74. Dry bulb: 58.0°F. Wet bulb: 53.3°F. Barometric pressure: 1030 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	14.62	33.47	306.5	5.82	0.54
10	14.76 P	33.47 2/	309.3	5.74	0.46
21	14.30	33.59	291.3	5.93	0.54
52	10.54	33.84 2/	204.0	6.19	0.64
105	8.90	33.95	170.0	5.91	0.91
216	8.66	33.95	166.5	5.85	0.91
323	7.44	34.02 2/	144.1	4.25	1.64
437	5.60	33.95	126.2	3.65	1.82
547	4.42	34.01 2/	108.9	2.48	2.82
663	4.20	34.10 2/	99.9	1.63	2.92
886	3.56	34.25	82.6	0.73	3.17
1097	3.12	34.35	71.0	0.54	3.40
1288 1305	2.78	34.43 2/	62.1	0.33	3.35

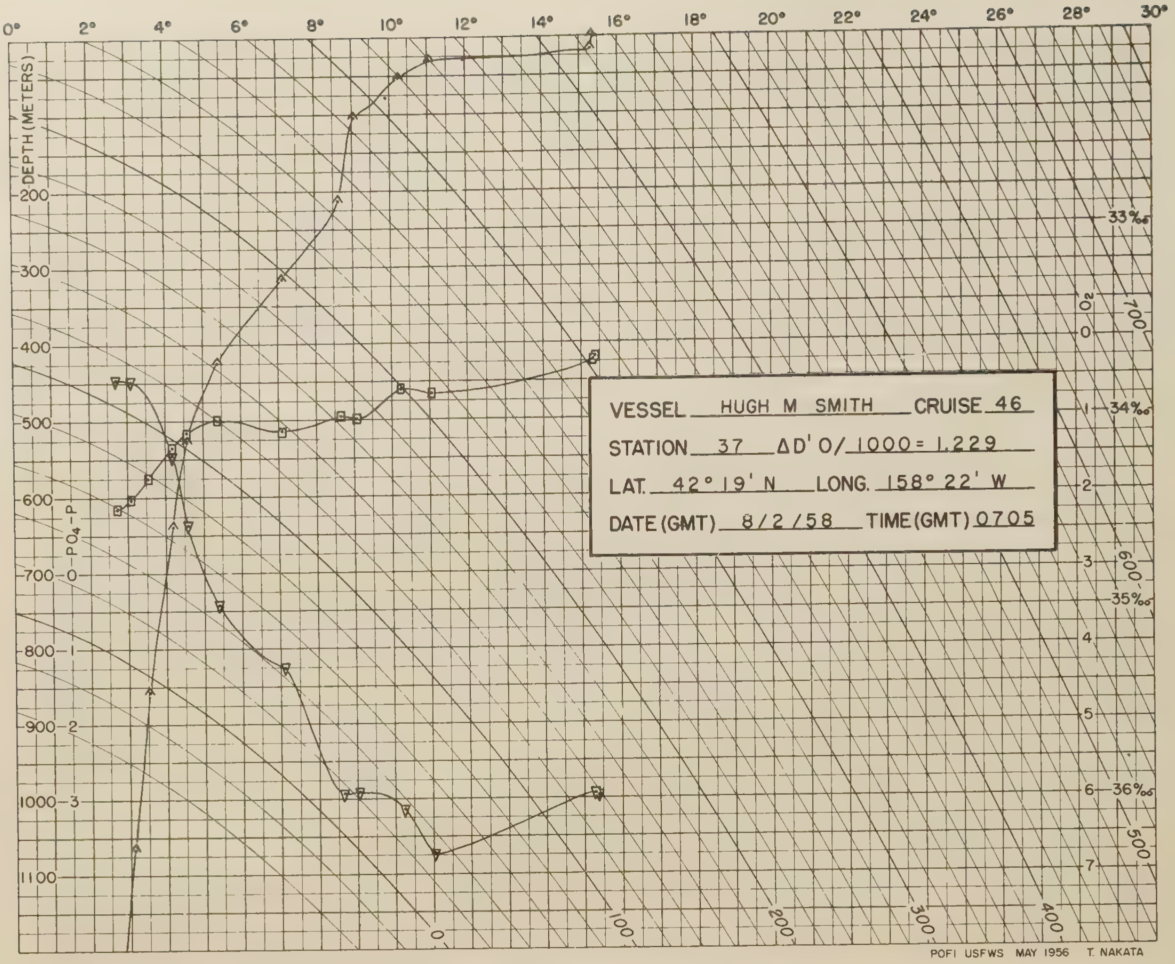
2/ Indicates H_2S precipitate in salinity sample.



Weather: 02, cloud coverage: 8. Wind: 000°, 07 kts. Sea: 1-3 ft. Wire angle: 04°. BT slide: 81. Dry bulb: 57.2°F. Wet bulb: 53.9°F. Barometric pressure: 1030 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	16.38	33.64	331.4	5.79	0.42
11	16.41 P	33.66	330.5	5.73	0.26
21	14.28	34.01	260.3	6.60	0.32
53	11.22	34.10	196.4	5.87	0.54
106	10.50	34.27 2/	171.6	5.60	0.76
216	9.21	34.11 2/	162.9	5.68	0.50
324	8.02	34.11	145.2	4.37	1.08
437	6.01	34.01	126.4	3.67	1.91
546	4.84	33.99	114.9	2.74	2.42
661	4.35	34.10	101.4	1.82	2.00
882	3.58	34.25 2/	82.7	0.73	2.82
1094	3.08	34.36	69.9	0.51	2.63
1305	2.70	34.44 2/	60.7	0.42	3.32

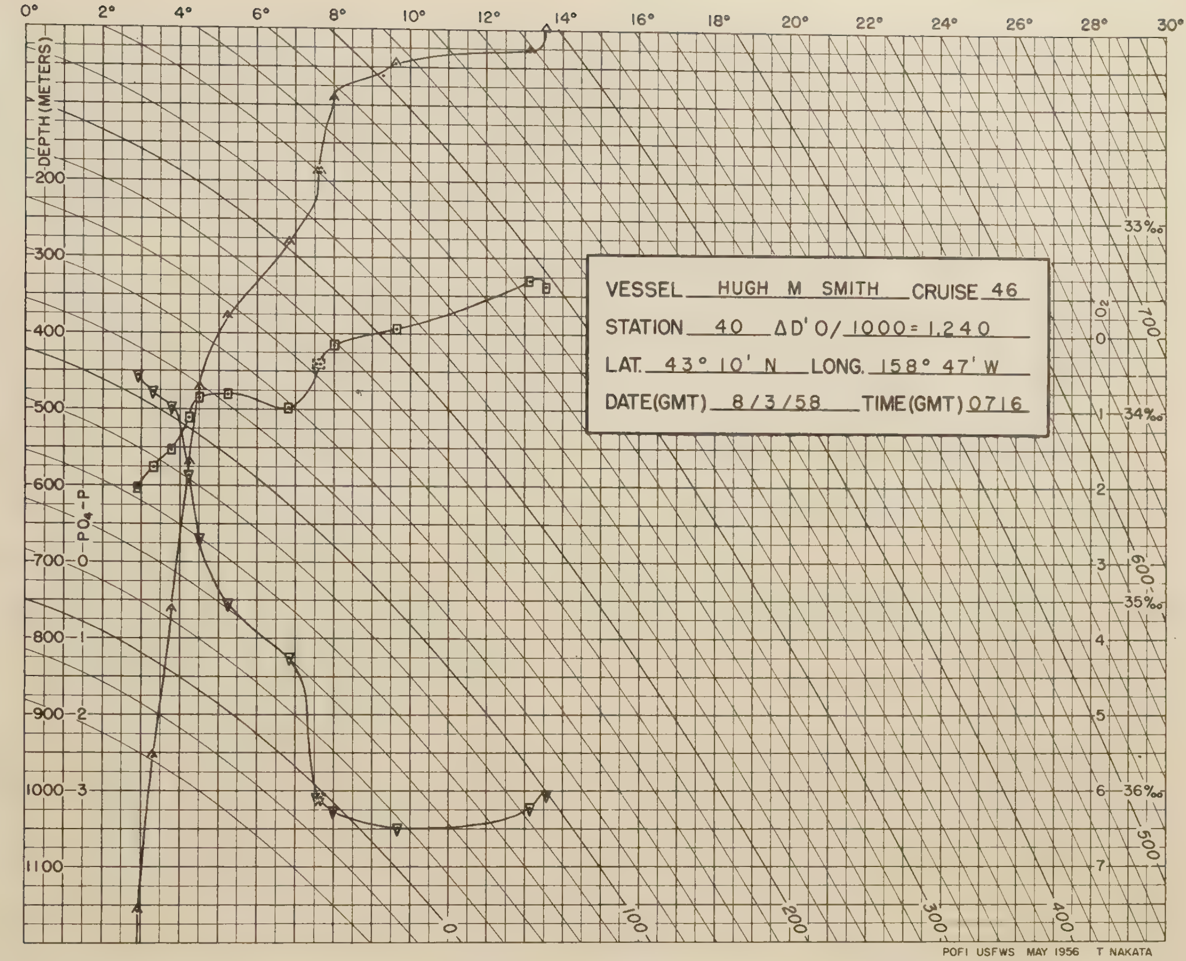
2/ Indicates H_2S precipitate in salinity sample.



Weather: 02, cloud coverage: not recorded. Wind: 350°, 08 kts. Sea: < 1 ft. Wire angle: 07°. BT slide: 89. Dry bulb: 54.5°F. Wet bulb: 52.2°F. Barometric pressure: 1032 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	15.36	33.67 2/	307.2	5.97	0.54
16	15.29	33.69	304.2	5.94	0.42
31	11.05	33.86 2/	211.0	6.72	0.54
52	10.24	33.84	199.1	6.13	0.64
103	9.05	33.99 2/	169.3	5.90	0.64
212	8.64	33.98 2/	164.0	5.92	0.12
315	7.08	34.05 2/	136.8	4.25	1.32
424	5.39	34.00 2/	120.1	3.42	2.52
529	4.58	34.06	106.8	2.37	2.92
639	4.19	34.14	96.7	1.45	2.92
857	3.55	34.30	78.7	1.66 P	2.92
1067	3.08	34.41 2/	66.1	0.48	3.25
1279	2.73	34.46	59.6	0.45	2.63

2/ Indicates H_2S precipitate in salinity sample.

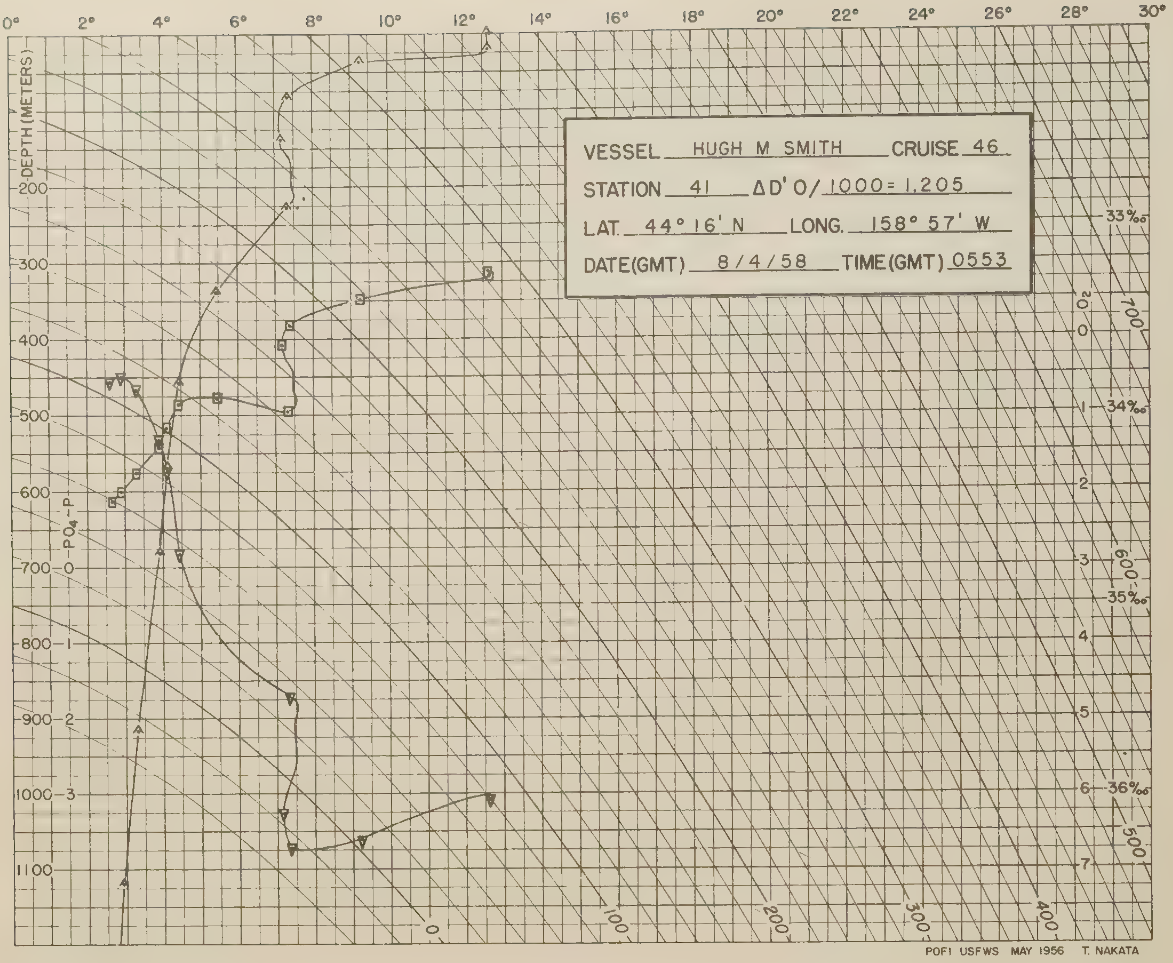


VESSEL HUGH M SMITH CRUISE 46
STATION 40 ΔD' 0/1000 = 1.240
LAT. 43° 10' N LONG. 158° 47' W
DATE(GMT) 8/3/58 TIME(GMT) 0716

Weather: 02, cloud coverage: 8. Wind: 280°, 13 kts. Sea: 3-5 ft. Wire angle: 27°. BT slide: 96. Dry bulb: 54.0°F. Wet bulb: 52.0°F. Barometric pressure: 1028 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	13.56	33.35	294.3	6.04	NG
14	13.60 P	33.30	298.8	6.02	0.83
28	13.13	33.32	288.2	6.22	1.00
46	9.65	33.57	209.8	6.49	1.00
92	7.99	33.66	178.3	6.27	1.08
189	7.64 7.56	33.76	166.2 165.0	6.08	1.08
281	6.82	33.99	138.2	4.24	2.00
378	5.25	33.92	124.5	3.54	3.09
472	4.50	33.94	115.0	2.69	3.40
570	4.22	34.04	104.6	1.85	3.56
762	3.78	34.21	87.6	0.95	3.72
955	3.30	34.30	76.4	0.77	4.10
1158	2.92	34.41 2/	64.7	0.54	3.90

2/ Indicates H_2S precipitate in salinity sample.



VESSEL HUGH M SMITH CRUISE 46

STATION 41 ΔD' 0/1000= 1.205

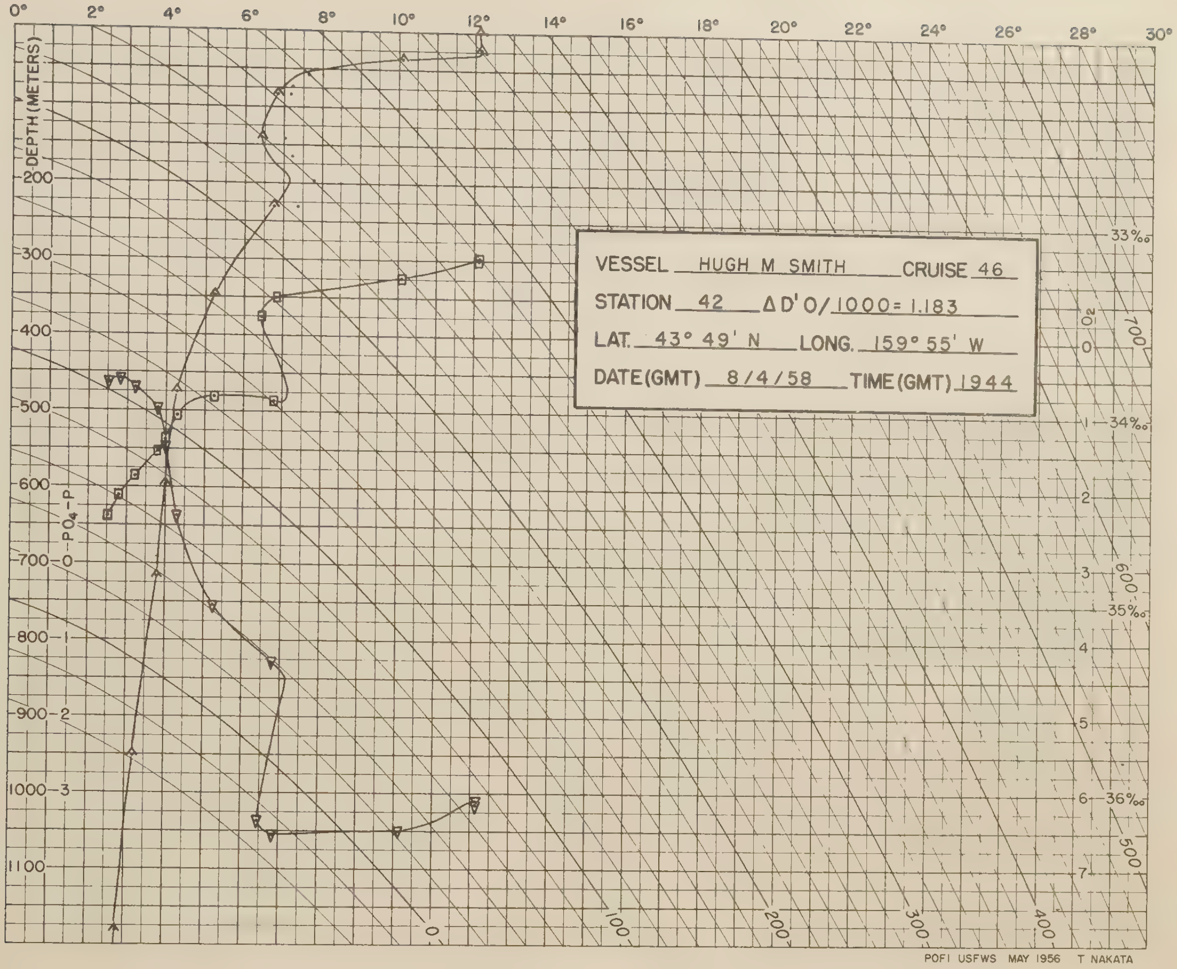
LAT. 44° 16' N LONG. 158° 57' W

DATE(GMT) 8/4/58 TIME(GMT) 0553

Weather: 63, cloud coverage: 9. Wind: 250°, 25 kts. Sea: 8-12 ft. Wire angle: 21°. BT slide: 102. Dry bulb: 55.6°F. Wet bulb: 54.7°F. Barometric pressure: 1020 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	12.62	33.25	283.9	6.09	0.54
20	12.64	33.27	282.8	6.63	0.64
36	9.23	33.39 2/	216.6	6.60	0.91
82	7.36	33.53	179.5	6.72	1.24
139	7.15	33.63	169.2	6.27	1.40
227	7.33	33.98	145.7	4.71	1.73
339	5.43	33.91	127.3	NS	2.52
457	4.43	33.94	114.5	2.82	2.73
569	4.11	34.06	102.0	1.72	3.40
682	3.89	34.17	91.6	1.32	3.40
917	3.31	34.30	76.5	0.66	3.40
1120	2.92	34.40	65.5	0.50	3.56
1328	2.65	34.45	59.6	0.56	3.48

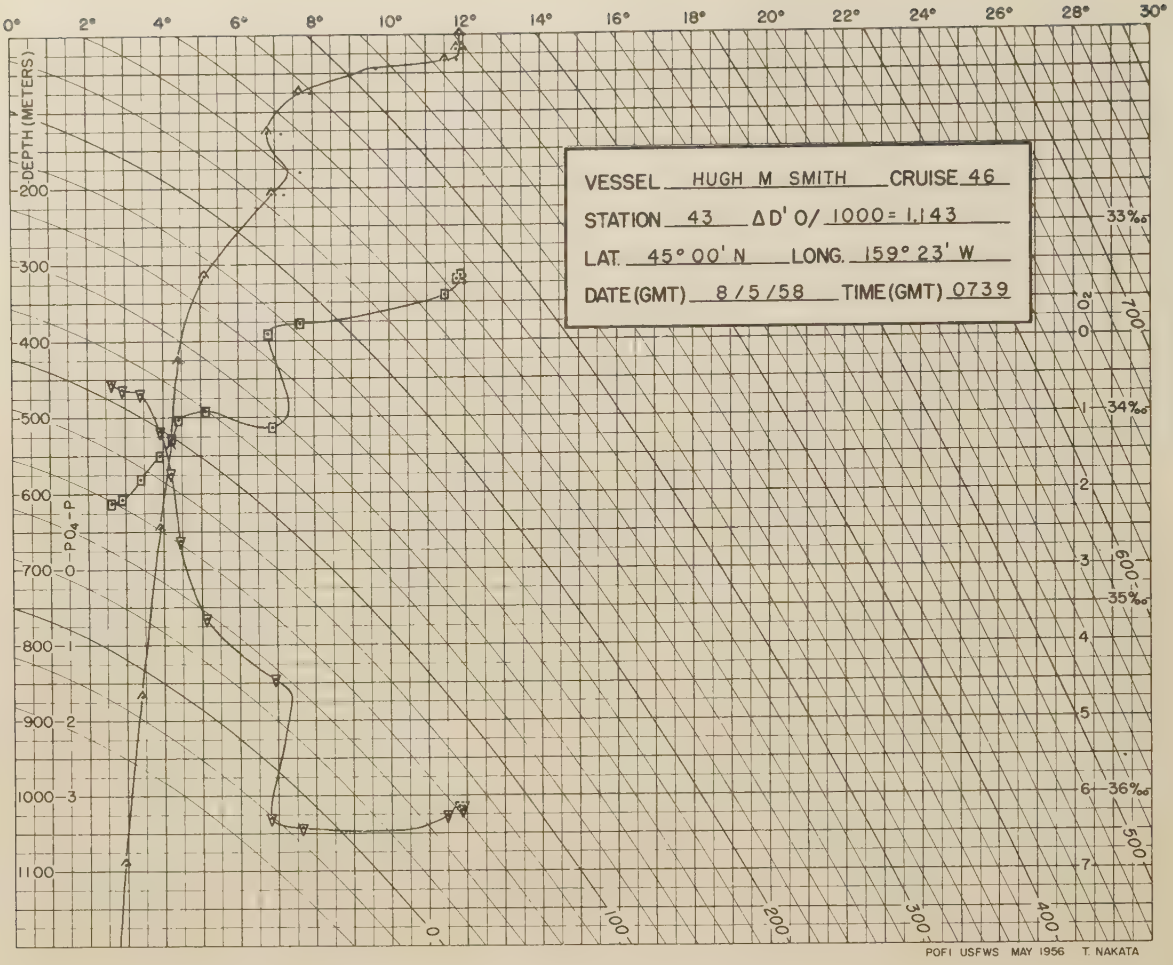
2/ Indicates H_2S precipitate in salinity sample.



Weather: 02, cloud coverage: 9. Wind: 250°, 22 kts. Sea: 8-12 ft. Wire angle: 06°. BT slide: 106. Dry bulb: 56.0°F. Wet bulb: 55.0°F. Barometric pressure: 1020 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, μg at. /L.
0	12.12	33.20 2/	278.4	6.14	0.83
21	12.15	33.19 2/	279.8	6.11	0.70
36	10.11	33.29 2/	237.9	6.50	0.70
83	6.82	33.40	182.0	6.54	1.00
141	6.44	33.50	169.9	6.36	1.00
230	6.78	33.94	141.3	4.29	1.48
348	5.23	33.92 2/	124.3	3.53	2.20
475	4.28	34.02 2/	106.7	2.37	2.63
596	3.98	34.15 2/	94.0	1.46	2.42
717	3.78	34.21	87.6	0.96	3.00
952	3.20	34.34	72.5	0.69	3.17
1181	2.80	34.44 2/	61.5	0.57	3.17
1394	2.53	34.55 2/	51.1	0.61	3.00

2/ Indicates H_2S precipitate in salinity sample.

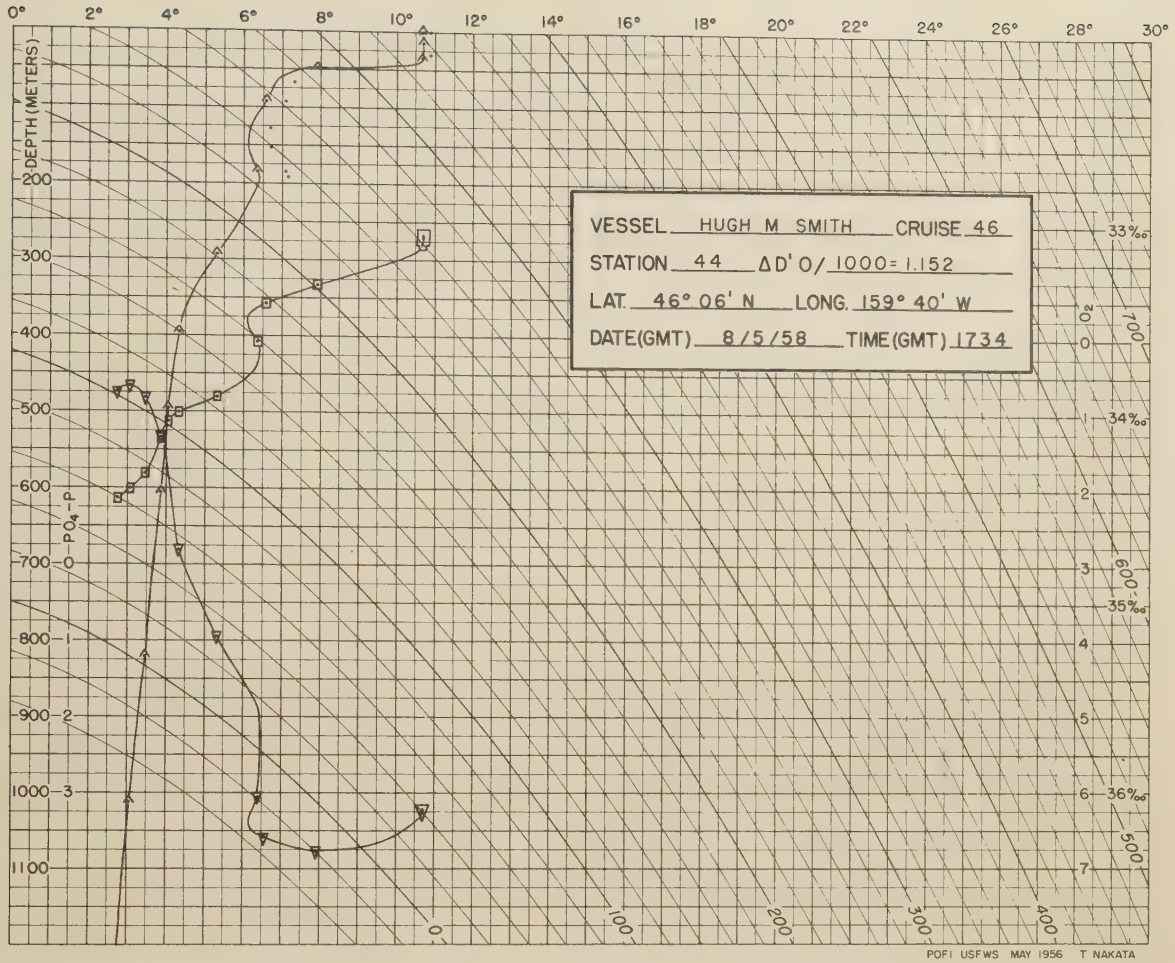


VESSEL HUGH M SMITH CRUISE 46
STATION 43 ΔD' 0/ 1000 = 1.143
LAT. 45° 00' N LONG. 159° 23' W
DATE (GMT) 8/5/58 TIME (GMT) 0739

Weather: 51, cloud coverage: 8. Wind: 290°, 17 kts. Sea: 8-12 ft. Wire angle: 25°. BT slide: 111. Dry bulb: 53.3°F. Wet bulb: 51.5°F. Barometric pressure: 1018 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	11.87	33.26	269.5	6.19	0.50
19	11.79 P 11.92 P	33.28	266.7 268.9	6.14	0.42
33	11.46	33.36 2/	254.9	6.27	0.42
76	7.62	33.51 2/	184.5	6.42	1.00
128	6.80	33.56	170.0	6.28	0.70 Q
209	6.90	34.05	134.4	4.44	1.64
315	5.13	33.97 2/	119.4	3.65	1.64
426	4.42	34.01 2/	108.9	2.61	2.20
534	4.22	34.11 2/	99.4	1.73	2.63
645	3.93	34.20	89.7	1.18	3.00
868	3.40	34.32 2/	75.8	0.68	3.00
1091	2.94	34.43 2/	63.4	0.63	3.17
1302	2.64	34.45 2/	59.5	0.54	3.09

2/ Indicates H_2S precipitate in salinity sample.



VESSEL HUGH M SMITH CRUISE 46
STATION 44 ΔD' 0/1000 = 1.152
LAT. 46° 06' N LONG. 159° 40' W
DATE (GMT) 8/5/58 TIME (GMT) 1734

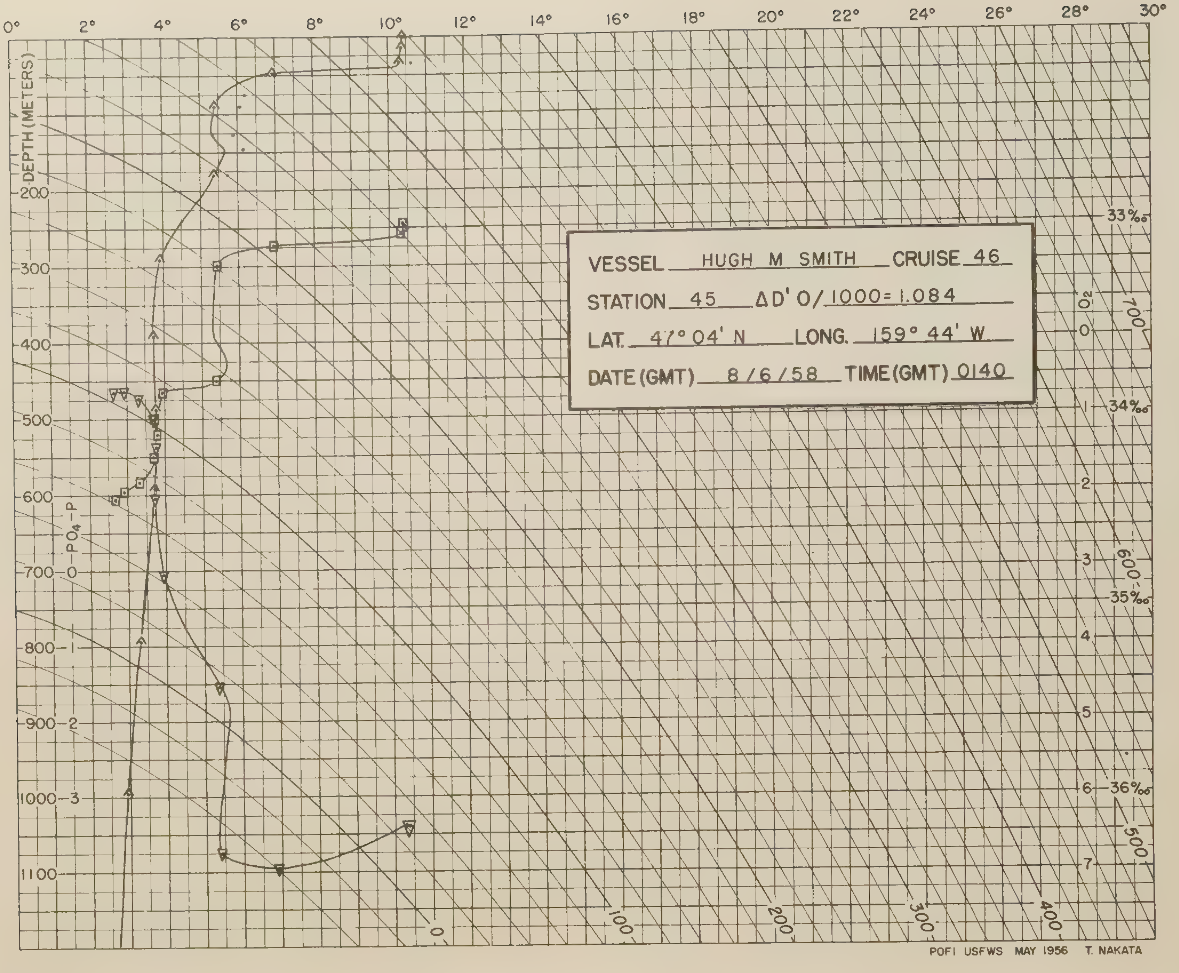
POFI USFWS MAY 1956 T NAKATA

Weather: 02, cloud coverage: 8. Wind: 290°, 19 kts. Sea: 3-5 ft. Wire angle: 23°. BT slide: 116. Dry bulb: 51.9°F. Wet bulb: 50.0°F. Barometric pressure: 1022 mbs.

Depth, m.	T, °C.	S, °/oo	δ_t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	10.68	33.07 2/	263.0	6.25	0.83
14	10.70	33.08	262.6	6.22	0.70
34	10.68	33.11	260.0	6.26	0.59
48	7.90	33.33 2/	201.7	6.77	0.59
92	6.57	33.43	176.8	6.58	0.76
184	6.38	33.63 2/	159.4	6.04 Q	0.50
293	5.33	33.92 2/	125.3	3.94	1.64
396	4.34	34.00 2/	108.7	2.80	2.41
496	4.03	34.05 2/	102.0	0.22 P	2.82
604	3.84	34.13	94.2	1.32	2.00
820	3.45	34.32 2/	76.3	0.81	2.82
1011	3.04	34.40	66.5	0.66	3.32
1211	2.74	34.45 2/	60.3	0.72	3.17* 2.63

2/ Indicates H_2S precipitate in salinity sample.

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.



VESSEL HUGH M SMITH CRUISE 46

STATION 45 ΔD' 0/1000= 1.084

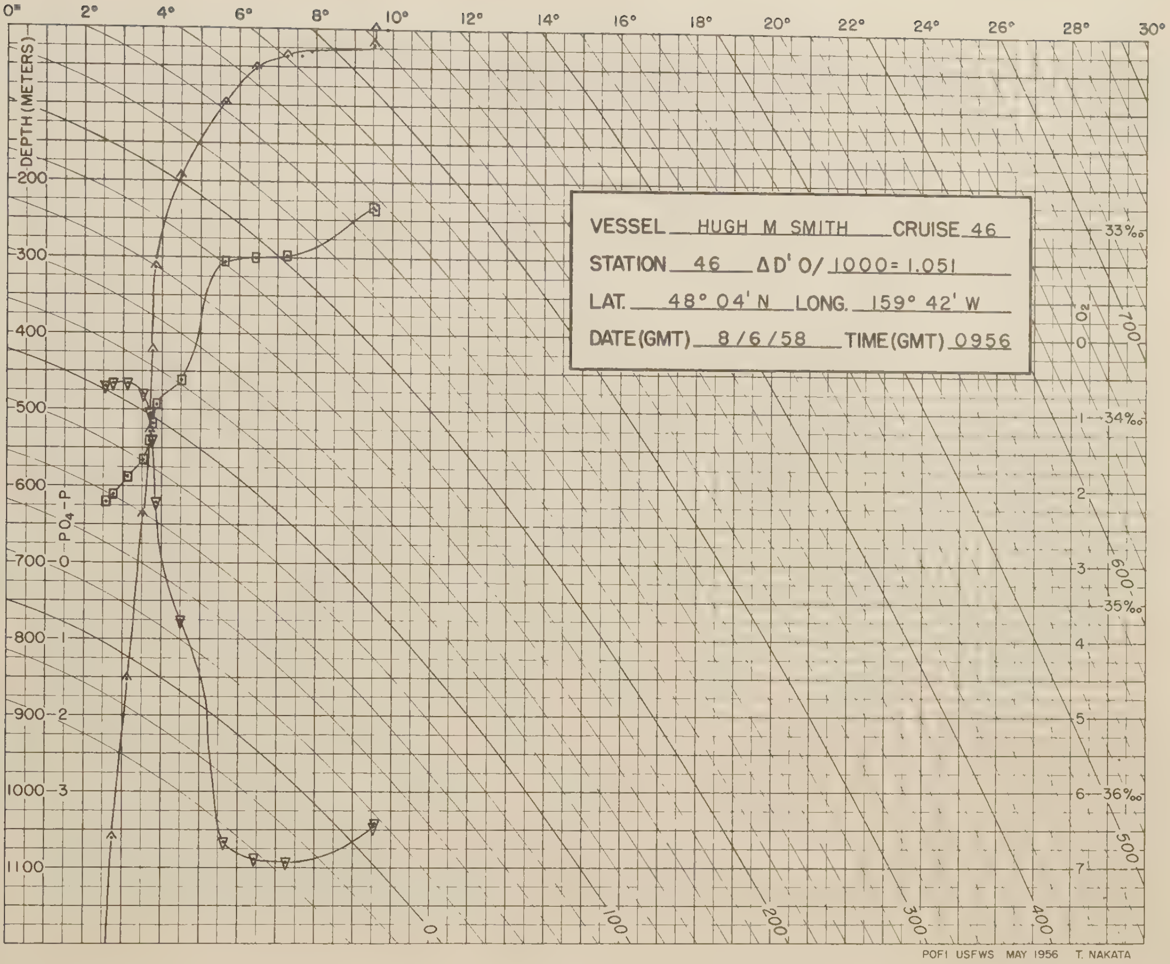
LAT. 47° 04' N LONG. 159° 44' W

DATE (GMT) 8/6/58 TIME (GMT) 0140

Weather: 03, cloud coverage: 8. Wind: 300°, 12 kts. Sea: 3-5 ft. Wire angle: 23°. BT slide: 122. Dry bulb: 52.0°F. Wet bulb: 50.0°F. Barometric pressure: 1024 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O_2, ml./L.	PO_4-P, µg at./L.
0	10.40	32.99 2/	264.5	6.39	1.48
14	10.36	32.98	264.5	6.40	1.00
33	10.30	33.03	259.9	6.38	0.83
47	6.91	33.09 2/	206.3	6.94	1.48
90	5.41	33.19 2/	180.8	6.75	1.48
180	5.38	33.80 2/	134.9	4.51	1.82
290	3.94	33.86 2/	115.4	3.04	2.82
391	3.72	34.00 2/	102.7	2.03	2.63
488	3.78	34.08	97.3	1.37	2.82
591	3.70	34.20 2/	87.6	1.00	3.32
794	3.32	34.33	74.3	0.72	3.00
994	2.93	34.38	67.1	0.63	3.17
1202	2.66	34.42	61.8	0.64	3.32

2/ Indicates H_2S precipitate in salinity sample.

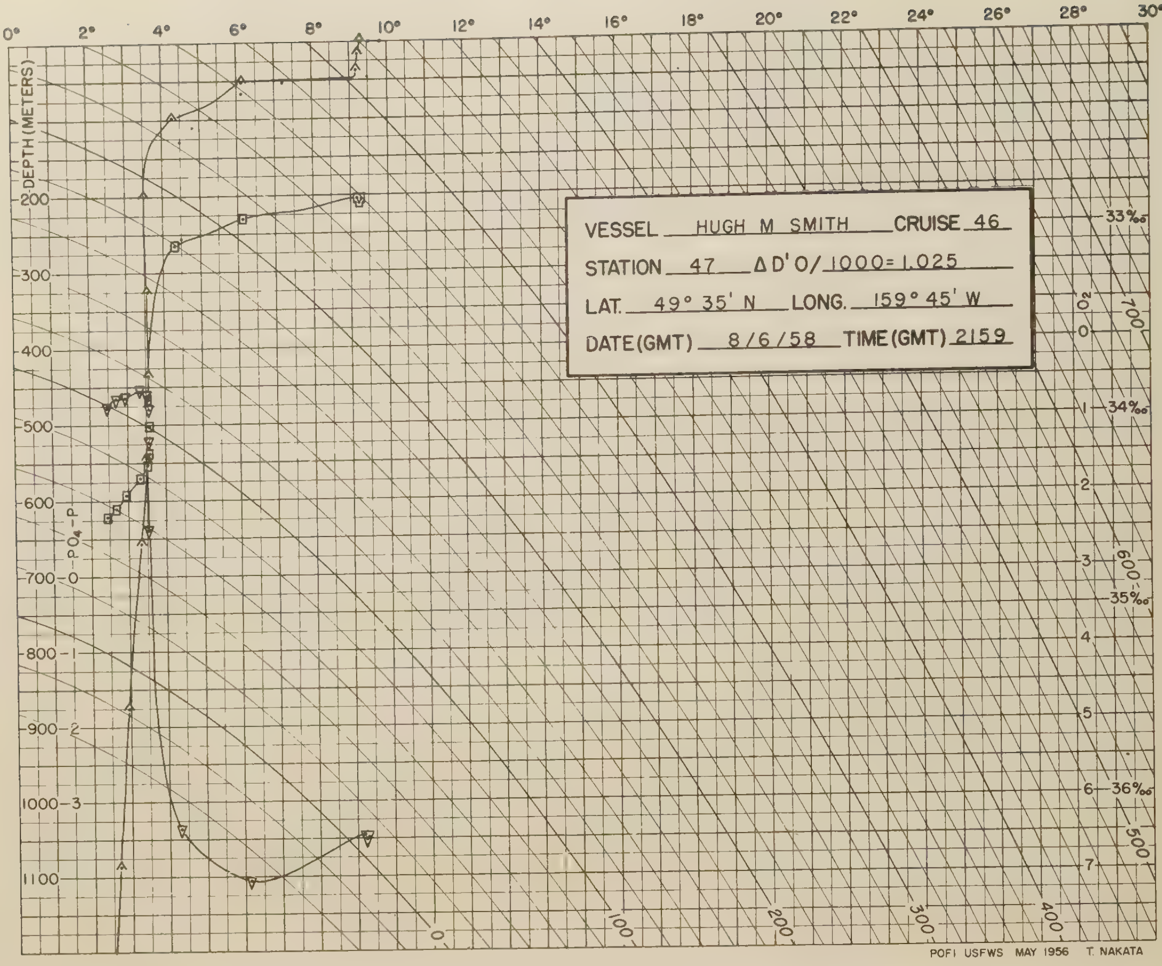


Weather: 02, cloud coverage: 8. Wind: 280°, 13 kts. Sea: 1-3 ft. Wire angle: 12°. BT slide: 127. Dry bulb: 50.5°F. Wet bulb: 49.4°F. Barometric pressure: 25 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	9.57	32.94	255.0	6.41	1.16
20	9.54	32.93	255.3	6.45	1.00
36	7.24	33.19	203.0	6.92	1.24
51	6.42	33.20	192.0	6.89	1.16
97	5.63	33.22	181.1	6.65	1.00
194	4.51	33.84	122.7	3.74	2.42
313	3.84	33.97	106.1	2.20	3.09
423	3.76	34.07 2/	97.9	1.40	3.40
528	3.68	34.16	90.4	1.01	2.42
638	3.52	34.26	81.5	0.79	3.17
853	3.12	34.35	71.0	0.65	3.17
1061	2.76	34.44	61.1	0.65	3.32
1271	2.56	34.48	56.6	0.69	3.48* 2.82

2/ Indicates H_2S precipitate in salinity sample.

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.

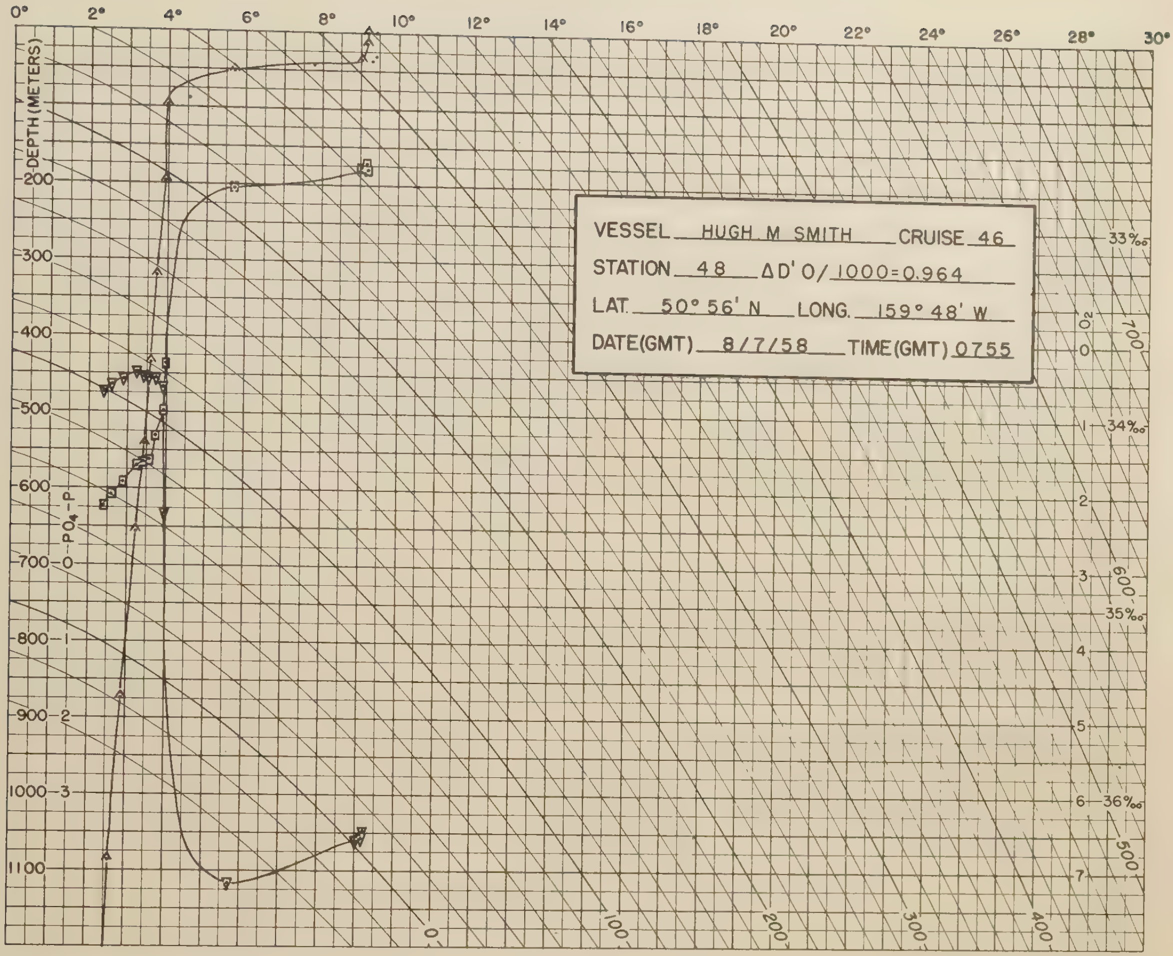


VESSEL HUGH M SMITH CRUISE 46
STATION 47 Δ D' O/1000 = 1.025
LAT. 49° 35' N LONG. 159° 45' W
DATE (GMT) 8/6/58 TIME (GMT) 2159

Weather: 02, cloud coverage: 8. Wind: 280°, 10 kts. Sea: 1-3 ft. Wire angle: 05°. BT slide: 131. Dry bulb: 51.0°F. Wet bulb: 49.0°F. Barometric pressure: 1025 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	9.28	32.82	259.7	6.48	1.82
16	9.22	32.84	257.2	6.50	1.82
37	9.17	32.82 2/	257.9	6.45	1.40
52	6.14	32.92	209.9	7.05	1.48
99	4.29	33.06	179.1	6.35	2.00
200	3.54	33.87 2/	110.8	2.39	3.32
324	3.57	34.01	100.7	1.24	3.81
437	3.58	34.15	90.3	0.79	4.00
544	3.49	34.21	84.9	0.61	3.40
657	3.33	34.28	78.2	0.56	3.25
876	2.95	34.37	68.0	0.63	3.64
1087	2.68	34.44	60.6	0.65	4.25
1297	2.44	34.48	55.6	0.77	3.72

2/ Indicates H_2S precipitate in salinity sample.



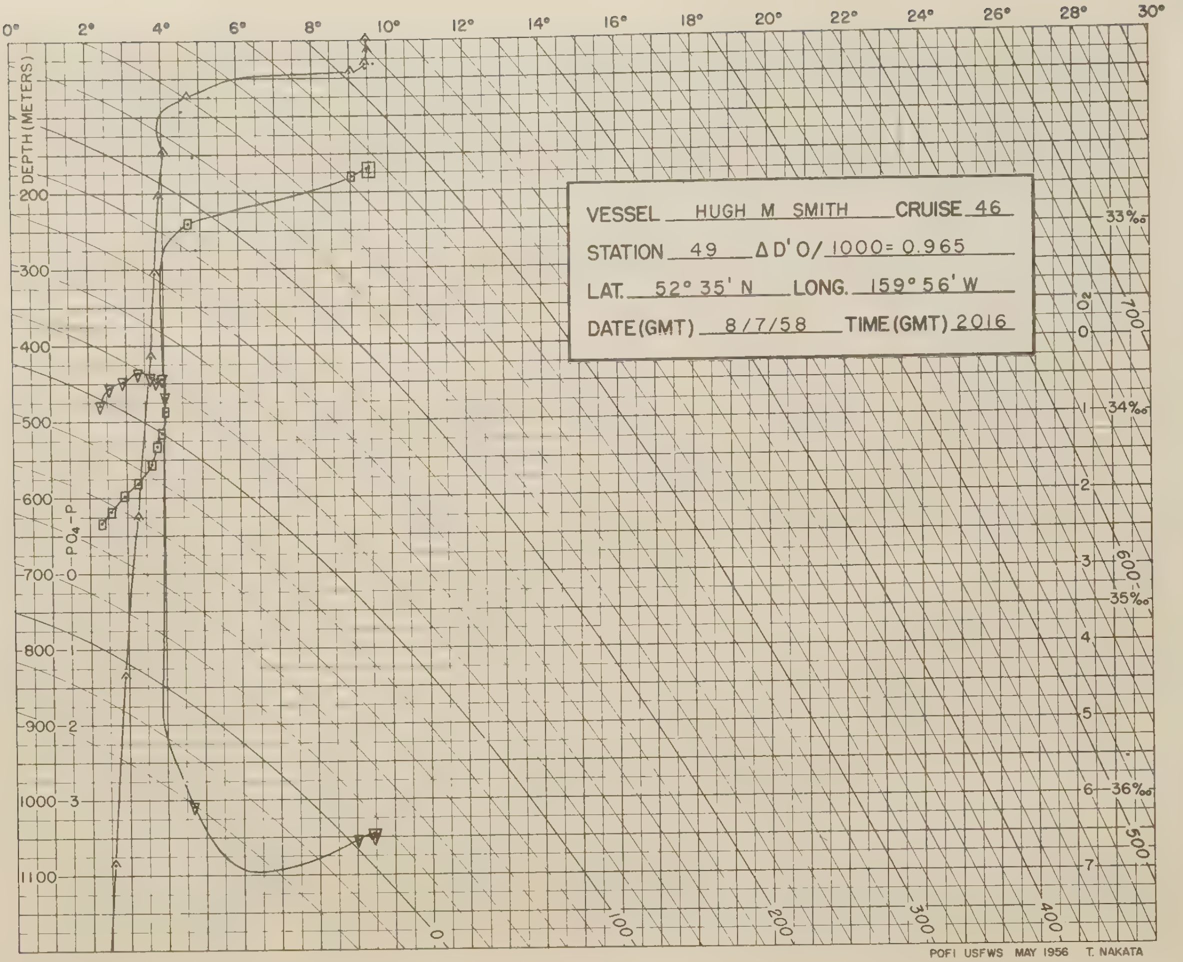
VESSEL HUGH M SMITH CRUISE 46
STATION 48 ΔD' 0/1000=0.964
LAT. 50° 56' N LONG. 159° 48' W
DATE(GMT) 8/7/58 TIME(GMT) 0755

POFI USFWS MAY 1956 T NAKATA

Weather: 02, cloud coverage: 8. Wind: 320°, 14 kts. Sea: 1-3 ft. Wire angle: 07°. BT slide: 134. Dry bulb: 49.9°F. Wet bulb: 47.4°F. Barometric pressure: 1028 mbs.

Depth, m.	T, ^{o}C.	S, ^{o}/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	9.20	32.72	265.9	6.47	1.64
15	9.18	32.69	267.8	6.56	1.16
36	9.03	32.71	264.1	6.60	1.48
51	5.69	32.82	211.8	7.16	1.32
98	3.98	33.74 2/	124.9	2.30	2.42
197	3.92	33.99	105.3	0.66	3.00
320	3.72	34.12	93.8	0.53	3.48
433	3.58	34.25 2/	82.7	0.53	3.81
541	3.42	34.26	80.5	0.53	3.25
654	3.24	34.28	77.4	0.47	3.32
874	2.87	34.36	68.1	0.57	3.48
1086	2.60	34.43	60.6	0.63	3.40
1301	2.40	34.49	54.5	0.73	3.56

2/ Indicates H_2S precipitate in salinity sample.

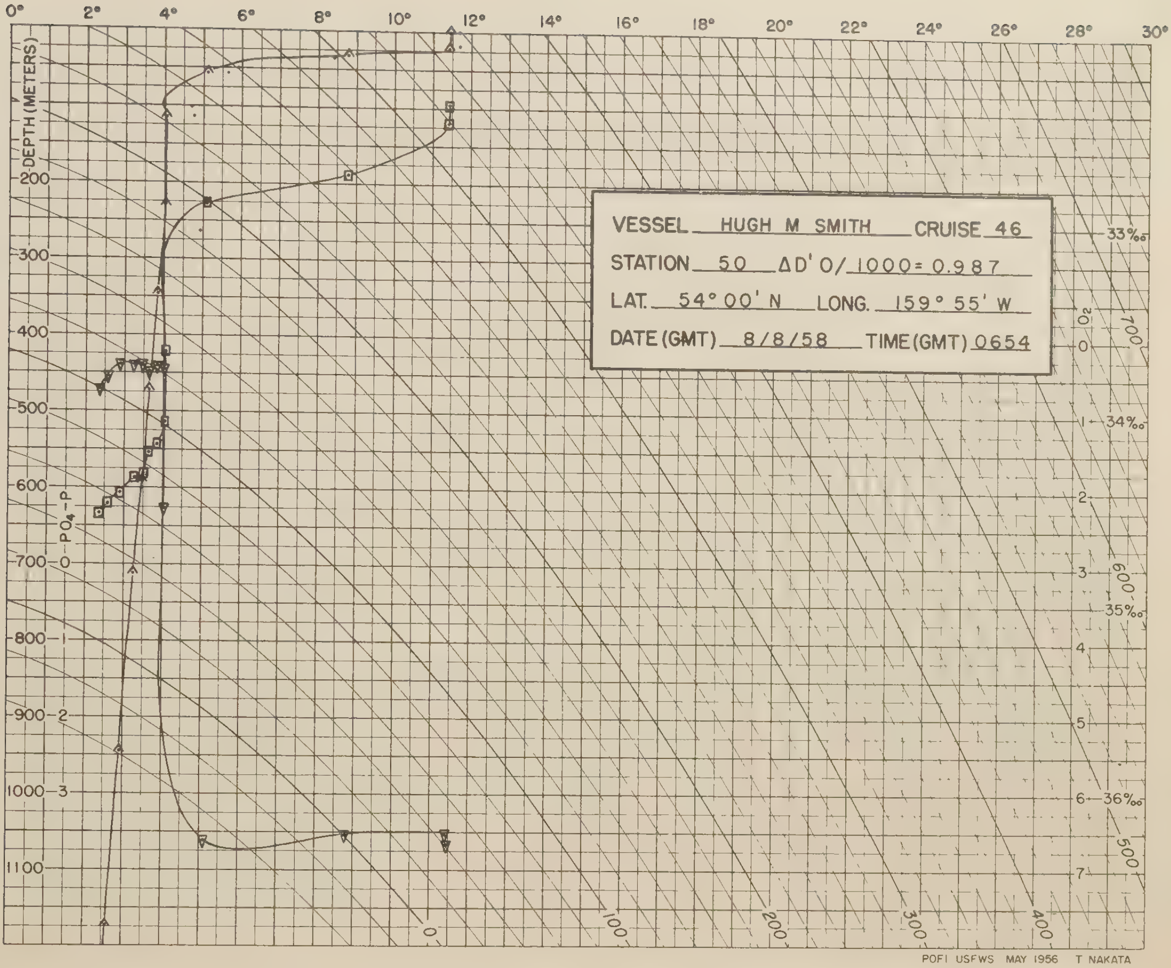


POFI USFWS MAY 1956 T. NAKATA

Weather: 02, cloud coverage: 8. Wind: 320°, 20 kts. Sea: 5-8 ft. Wire angle: 1st cast 27°, 2nd cast 31°. BT slide: 1st cast 138, 2nd cast 139. Dry blub: 1st cast 50.6°F, 2nd cast 50.3°F. Wet blub: 1st cast 49.7°F, 2nd cast 48.9°F. Barometric pressure: 1028 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	9.48	32.67	273.7	6.47	0.83
14	9.48	32.70	271.4	6.46	0.64
32	9.42	32.68	272.0	6.46	0.70
42	9.02	32.72 2/	263.2	6.53	0.70
74	4.70	32.96 2/	190.8	6.09	1.64
148	4.02	33.94	110.2	0.68	2.63
204	3.93	34.06	100.3	0.44	3.64
306	3.79	34.13	93.7	0.48	3.48
415	2.64	34.22 2/	85.5	0.41	3.48
625	3.28	34.32 2/	74.7	0.36	3.64
836	2.93	34.39	66.4	0.48	3.64
1086	2.58	34.47	57.5	0.54	3.48
1302	2.34	34.53 2/	51.0	0.78	3.35

2/ Indicates H_2S precipitate in salinity sample.



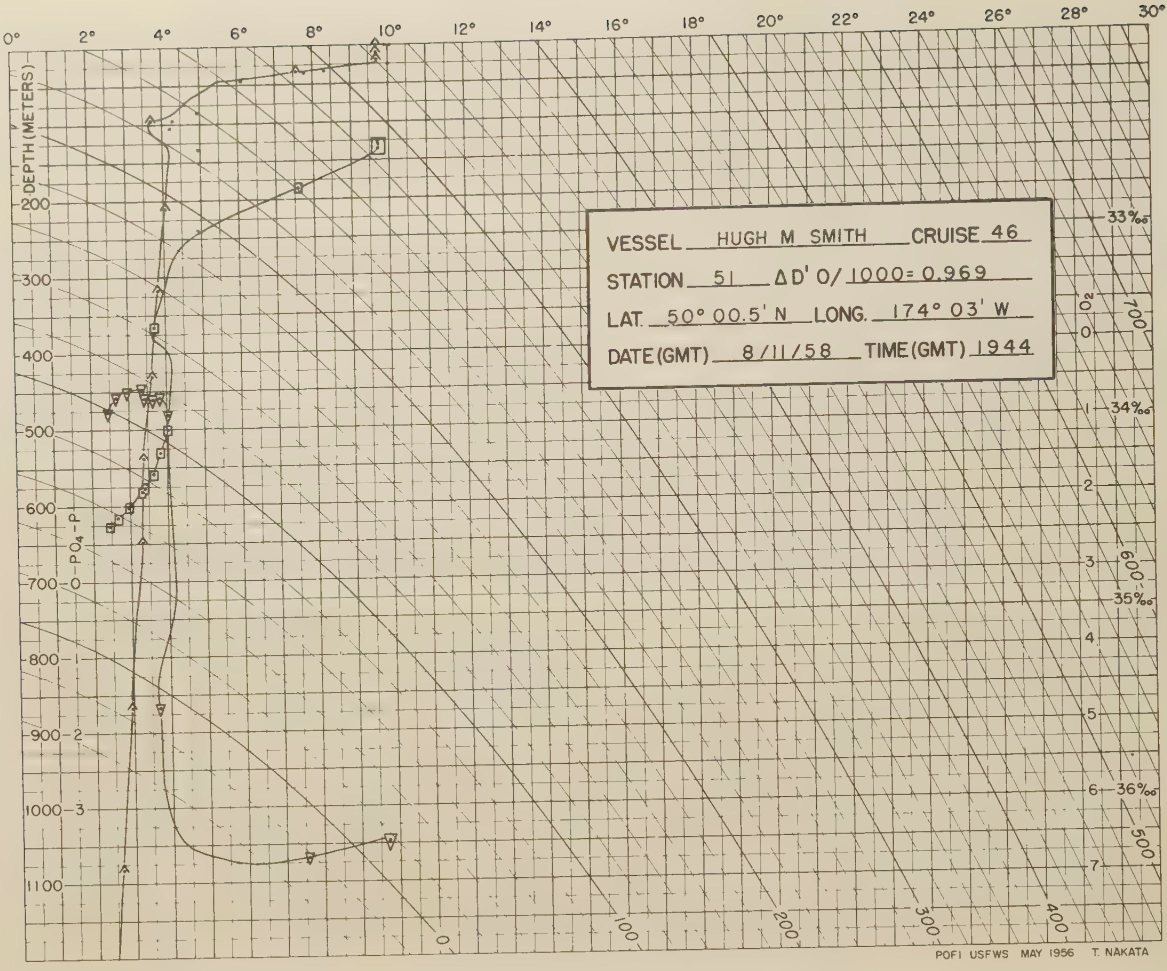
VESSEL HUGH M SMITH CRUISE 46
STATION 50 ΔD' 0/1000 = 0.987
LAT. 54° 00' N LONG. 159° 55' W
DATE (GMT) 8/8/58 TIME (GMT) 0654

Weather: 02, cloud coverage: 8. Wind: 290°, 14 kts. Sea: 3-5 ft. Wire angle: 07°. BT slide: 142. Dry bulb: 52.8°F. Wet bulb: 50.7°F. Barometric pressure: 1025 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	11.43	32.38 2/	326.9	6.65	0.32
21	11.41	32.48 2/	319.0	6.52	0.42
31	8.80	32.75 2/	257.7	6.53	1.48
57	5.11	32.91	198.8	6.60	1.91
114	4.04	33.69 2/	129.2	2.26	3.17
229	4.02	34.05 2/	101.8	0.44	3.32
346	3.83	34.17 2/	91.1	0.40	3.00
471	3.63	34.21 2/	86.2	0.48	3.09
591	3.46	34.32 2/	76.4	0.40	2.62
711	3.24	34.34	72.8	0.39	3.32
944	2.90	34.42 2/	63.8	0.39	3.81
1172	2.58	34.48	56.7	0.53	3.48
1384	2.37	34.53 2/	51.2	0.71	3.00* 3.81

2/ Indicates H_2S precipitate in salinity sample.

*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.

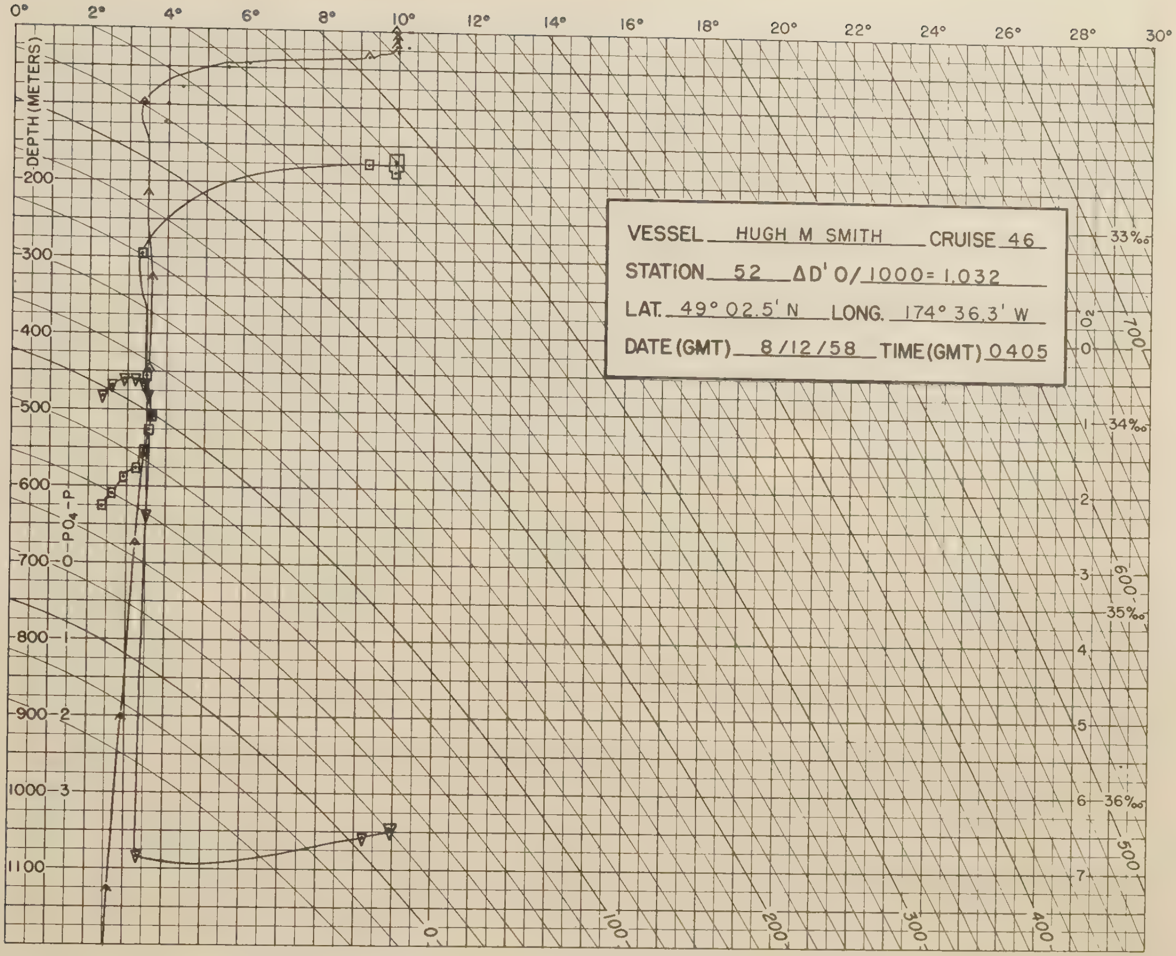


VESSEL HUGH M SMITH CRUISE 46
STATION 51 ΔD' 0/1000 = 0.969
LAT. 50° 00.5' N LONG. 174° 03' W
DATE (GMT) 8/11/58 TIME (GMT) 1944

Weather: 01, cloud coverage: 1. Wind: 250°, 24 kts. Sea: 5-8 ft. Wire angle: 22°. BT slide: 168. Dry bulb: 53.0°F. Wet bulb: 50.3°F. Barometric pressure: 1014 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, μg at. /L.
0	9.70	32.51	288.9	6.48	0.91
10	9.72	32.52	288.5	6.45	0.83
19	9.71	32.54	286.9	6.48	0.91
33	7.58	32.74 2/	241.1	6.68	1.48
96	3.69	33.46	143.1	4.67	2.82
211	4.03	34.00	105.7	0.80	3.32
318	3.81	34.12 2/	94.6	0.58	3.48
430	3.62	34.23	84.6	0.60	3.72
539	3.39	34.31 2/	76.5	0.59	3.64
649	3.32	34.32	75.1	0.47	3.64
867	2.96	34.41	65.0	0.50	0.50 P
1082	2.66	34.46	58.9	0.58	3.48
1288	2.44	34.50	54.1	0.76	3.85

2/ Indicates H_2S precipitate in salinity sample.



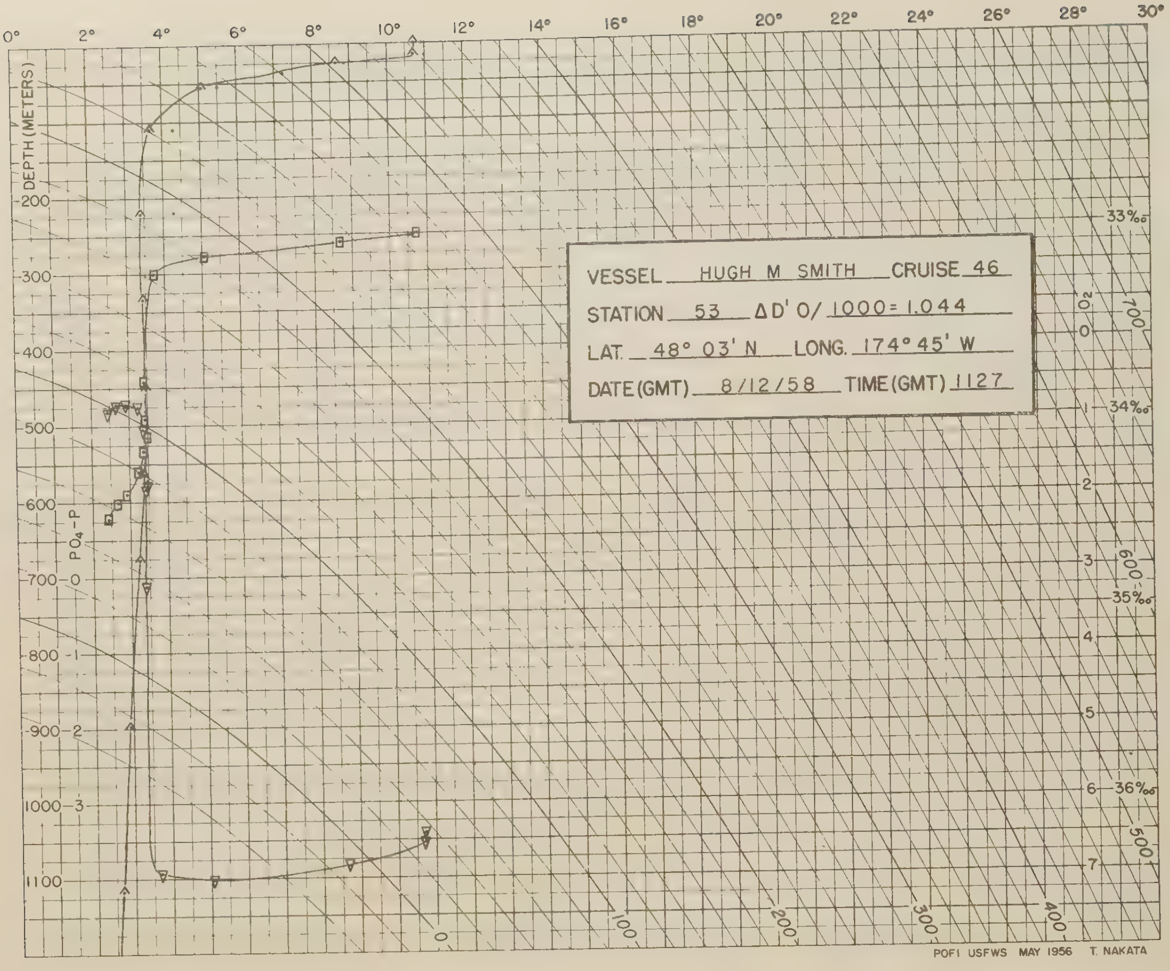
VESSEL HUGH M SMITH CRUISE 46
STATION 52 ΔD' 0/1000= 1.032
LAT. 49° 02.5' N LONG. 174° 36.3' W
DATE (GMT) 8/12/58 TIME (GMT) 0405

POFI USFWS MAY 1956 T NAKATA

Weather: 45, cloud coverage: 9. Wind: 280°, 20 kts. Sea: 5-8 ft. Wire angle: 20°. BT slide: 172. Dry bulb: 52.1°F. Wet bulb: 50.6°F. Barometric pressure: 1019 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	9.94	32.74 2/	275.7	6.45	1.16
10	9.96	32.68	280.3	6.48	1.16
20	9.96	32.70 2/	278.9	6.49	1.08
34	9.22	32.70	267.7	6.58	1.48
99	3.36	33.18	161.4	6.83	1.82
218	3.48	33.82	114.1	2.36	3.32
329	3.61	34.03 2/	99.6	1.04	3.81
447	3.55	34.10 2/	93.8	0.80	3.81
561	3.41	34.22 2/	83.5	0.64	3.48
676	3.22	34.26 2/	78.8	0.60	3.48
903	2.90	34.35	69.2	0.59	3.48
1128	2.60	34.44 2/	59.9	0.68	3.48
1339	2.36	34.50 2/	53.3	0.81	3.40

2/ Indicates H_2S precipitate in salinity sample.

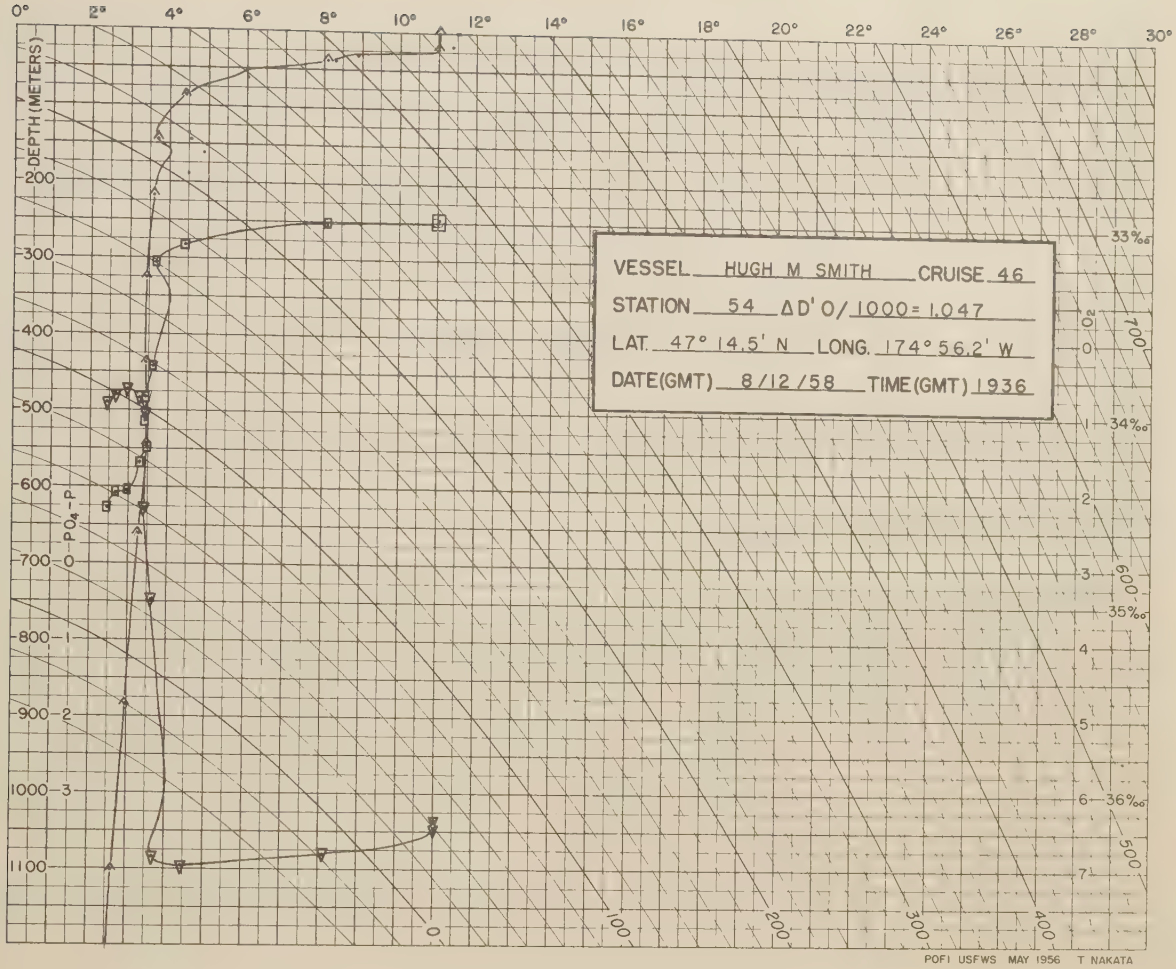


VESSEL HUGH M SMITH CRUISE 46
STATION 53 ΔD' 0/1000=1.044
LAT. 48° 03' N LONG. 174° 45' W
DATE (GMT) 8/12/58 TIME (GMT) 1127

Weather: 47, cloud coverage: 9. Wind: 290°, 18 kts. Sea: 3-5 ft. Wire angle: 18°. BT slide: 177. Dry bulb: 52.5°F. Wet bulb: 51.8°F. Barometric pressure: 1025 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	10.72	33.00 2/	268.9	6.41	1.16
15	10.72	33.00 2/	268.9	6.53	1.32
25	8.66	33.04 2/	233.9	6.83	1.48
55	5.06	33.11	183.1	7.01	1.64
110	3.68	33.20	162.7	6.92	1.82
221	3.40	33.77 2/	117.3	3.12	3.00
333	3.42	33.96 2/	103.1	1.83	3.48
451	3.46	34.06	96.0	1.78	3.48
564	3.38	34.13	90.0	1.03	3.64
677	3.23	34.24 2/	80.3	0.75	3.64
897	2.92	34.36 2/	68.6	0.71	3.64
1116	2.66	34.40	63.4	0.72	3.81
1323	2.42	34.49	54.7	0.81	3.90

2/ Indicates H_2S precipitate in salinity sample.



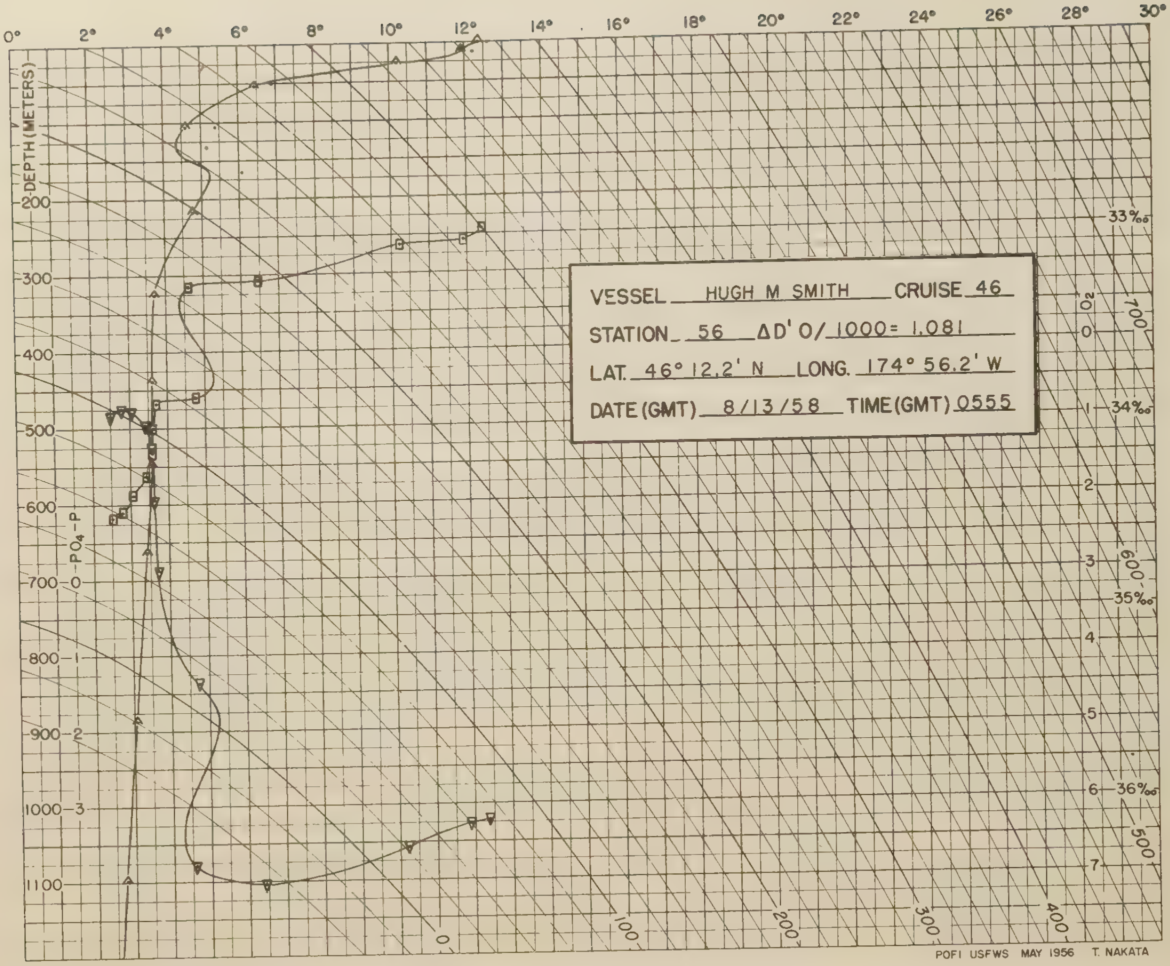
VESSEL HUGH M SMITH CRUISE 46
STATION 54 ΔD'0/1000 = 1.047
LAT. 47° 14.5' N LONG. 174° 56.2' W
DATE(GMT) 8/12/58 TIME (GMT) 1936

POFI USFWS MAY 1956 T NAKATA

Weather: 01, cloud coverage: 2. Wind: 280°, 10 kts. Sea: 1-3 ft. Wire angle: 00°. BT slide: 182. Dry bulb: 56.4°F. Wet bulb: 54.0°F. Barometric pressure: 1024 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	11.05	32.99 2/	275.2	6.35	1.40
21	11.01	33.00 2/	273.9	6.45	1.24
38	8.10	33.01 2/	228.3	6.80	1.56
85	4.42	33.13 2/	175.1	6.95	1.82
144	3.67	33.22	160.9	6.83	2.00
218	3.61	33.77 2/	119.1	3.47	3.09
325	3.43	33.93	105.4	2.27	3.48
437	3.42	34.05 2/	96.4	1.49	3.25
545	3.46	34.19 2/	86.1	1.09	3.48
660	3.27	34.27 2/	78.3	0.83	3.56
884	2.96	34.42 2/	64.3	0.72	3.52
1101	2.66	34.43 2/	61.1	0.80	3.56
1313	2.44	34.51 2/	53.4	0.89	3.64

2/ Indicates H_2S precipitate in salinity sample.

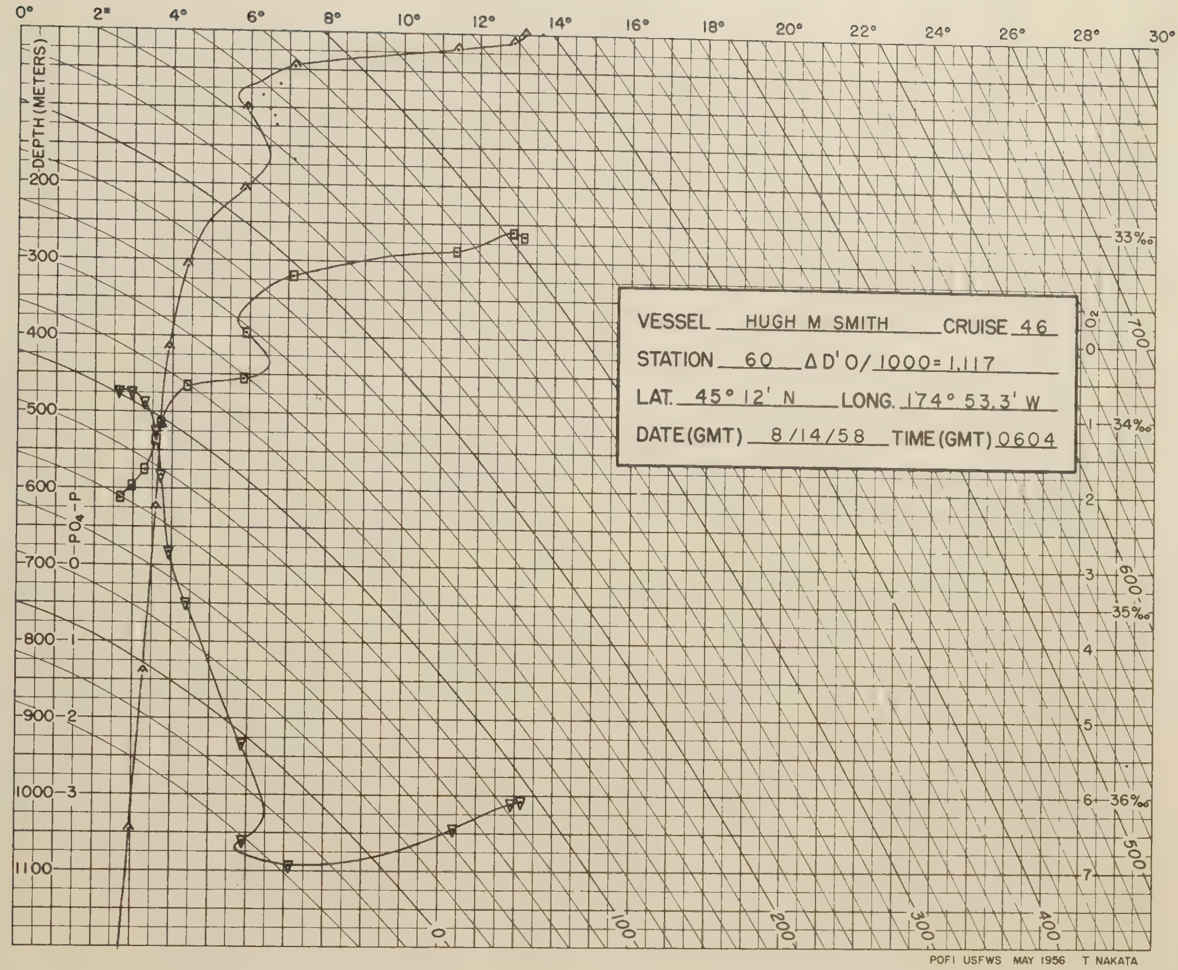


VESSEL HUGH M SMITH CRUISE 46
STATION 56 ΔD' 0/1000= 1.081
LAT. 46° 12.2' N LONG. 174° 56.2' W
DATE (GMT) 8/13/58 TIME (GMT) 0555

Weather: 47, cloud coverage: 4. Wind: 280°, 10 kts. Sea: 1-3 ft. Wire angle: 04°. BT slide: 187. Dry bulb: 55.0°F. Wet bulb: 53.9°F. Barometric pressure: 1026 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	12.38	32.97	300.1	6.21	1.48
11	11.88	33.03	286.7	6.26	1.32
27	10.22	33.05	257.1	6.57	1.32
53	6.43	33.23 2/	189.9	7.03	1.48
106	4.60	33.26	167.1	6.79	1.64
218	4.76	33.84	125.2	4.37	2.63
325	3.71	33.87	112.4	2.87	3.17
438	3.61	34.00	101.8	1.93	3.81
548	3.58	34.13 2/	91.7	1.27	3.81
663	3.41	34.25 2/	81.2	0.96	4.25
886	3.06	34.35	70.4	0.79	3.64
1099	2.78	34.44	61.3	0.73	3.81
1310	2.50	34.47	56.8	0.83	3.56

2/ Indicates H_2S precipitate in salinity sample.

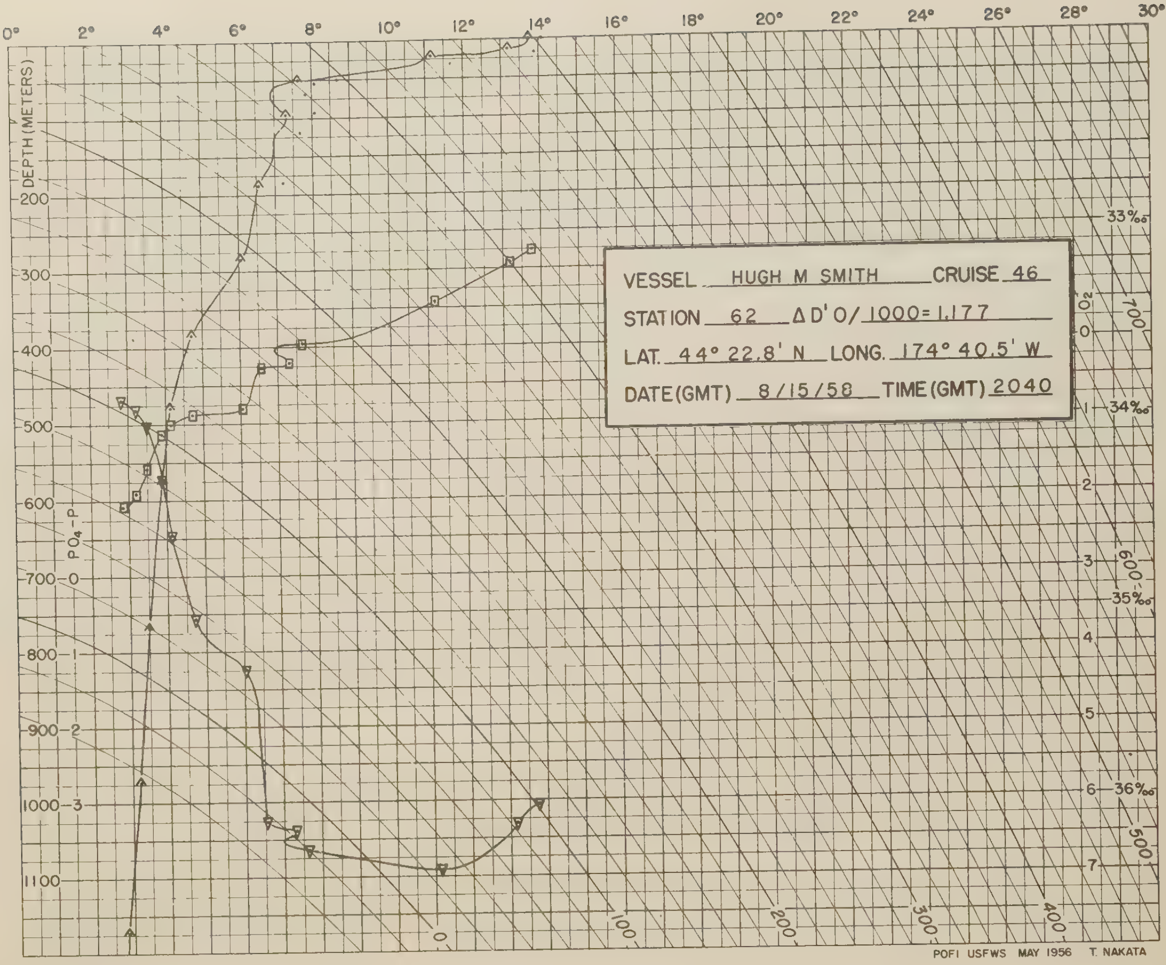


VESSEL HUGH M SMITH CRUISE 46
STATION 60 Δ D' 0/1000 = 1.117
LAT. 45° 12' N LONG. 174° 53.3' W
DATE (GMT) 8/14/58 TIME (GMT) 0604

Weather: 40, cloud coverage: 8. Wind: 320°, 06 kts. Sea: 1-3 ft. Wire angle: 16°. BT slide: 195. Dry bulb: 56.5°F. Wet bulb: 55.0°F. Barometric pressure: 1027 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	13.18	33.06 2/	308.3	6.08	1.32
10	12.87	33.04	304.0	6.11	1.40
20	11.40	33.14 2/	270.1	6.44	1.48
45	7.12	33.28 2/	195.0	6.92	1.64
101	5.88	33.58	157.1	6.60	1.48
207	5.84	33.82	138.6	5.33	2.00
308	4.39	33.86 2/	120.0	3.49	3.00
415	3.92	34.21 2/ P	88.9	2.81	3.32
518	3.71	34.06	98.2	1.81	3.64
627	3.58	34.14	91.0	1.28	3.90
839	3.27	34.30 2/	76.1	0.87	3.81
1046	2.95	34.39	66.5	0.73	4.25
1257	2.65	34.45 2/	59.6	0.71	4.10

2/ Indicates H_2S precipitate in salinity sample.

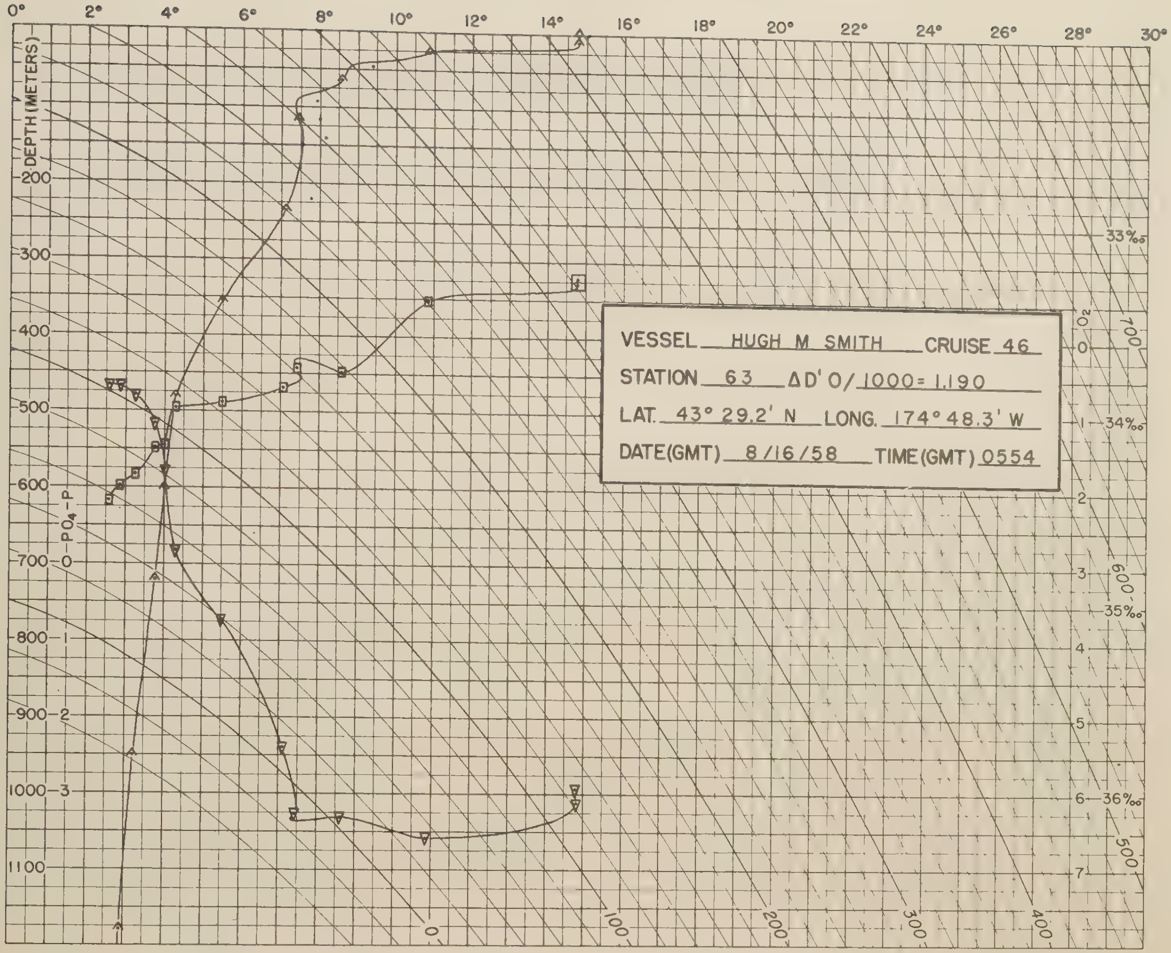


VESSEL HUGH M SMITH CRUISE 46
STATION 62 Δ D' O/1000= 1.177
LAT. 44° 22.8' N LONG. 174° 40.5' W
DATE (GMT) 8/15/58 TIME (GMT) 2040

Weather: 45, cloud coverage: 9. Wind: 010°, 22 kts. Sea: 3-5 ft. Wire angle: 32°.
BT slide: 202. Dry bulb: 59.0°F. Wet bulb: 57.2°F. Barometric pressure: 1016 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	13.75	33.10	316.3	6.06	1.00
13	13.18	33.17 2/	300.2	6.30	0.83
21	11.18	33.37 2/	249.4	6.92	0.83
50	7.64	33.58 2/	179.6	6.63	1.32
94	7.31	33.68 2/	167.7	6.38	1.48
188	6.56	33.71 2/	155.7	6.26	1.32
283	6.03	33.92	133.5	4.22	2.41
383	4.73	33.95 2/	116.8	3.56	2.62
479	4.14	34.00 2/	106.7	2.44	3.48
576	3.88	34.05	100.6	1.73	3.64
769	3.50	34.23	83.5	1.02	3.64
972	3.20	34.36	71.0	0.80	4.00
1173	2.83	34.43	62.5	0.68	4.10

2/ Indicates H_2S precipitate in salinity sample.



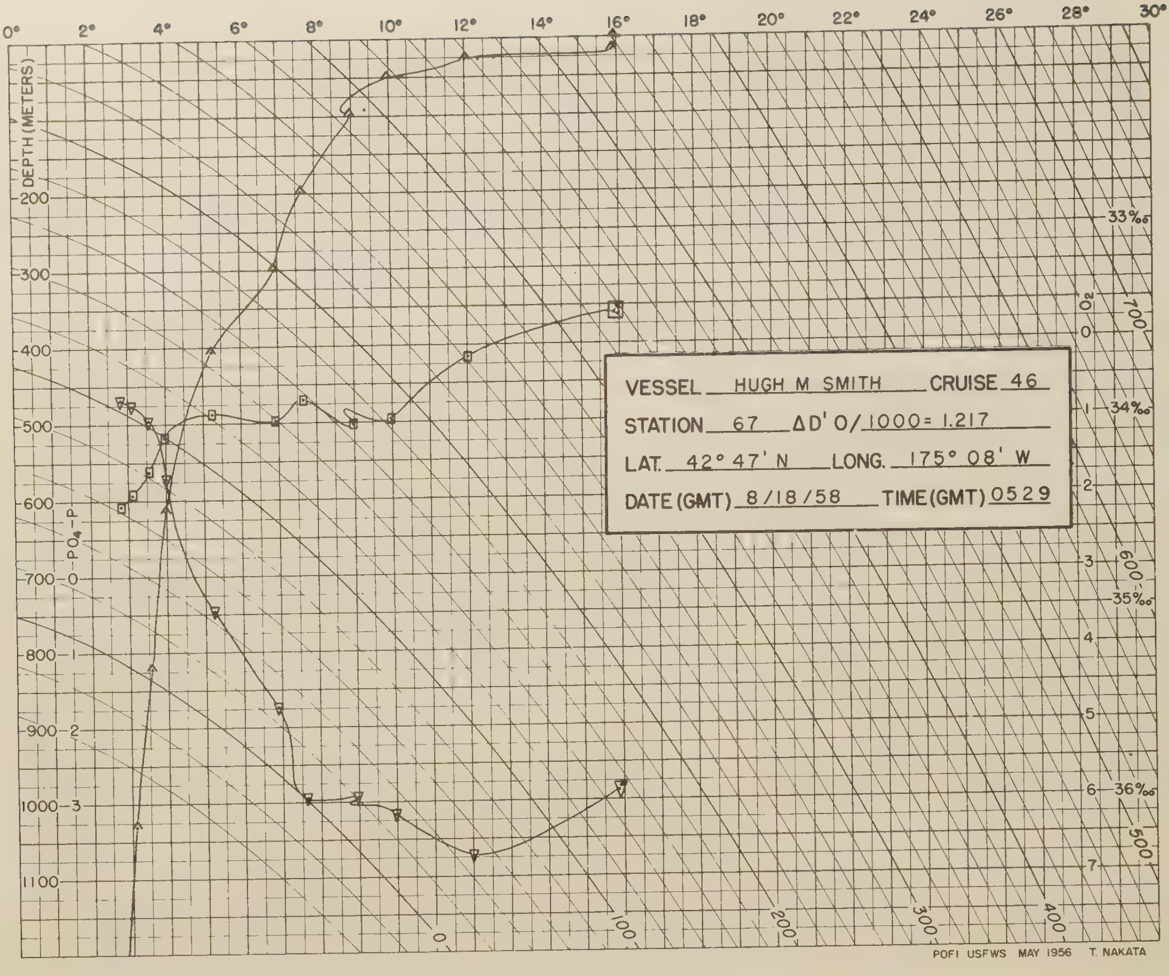
VESSEL HUGH M SMITH CRUISE 46
STATION 63 ΔD' 0/1000 = 1.190
LAT. 43° 29.2' N LONG. 174° 48.3' W
DATE (GMT) 8/16/58 TIME (GMT) 0554

POFI USFWS MAY 1956 T NAKATA

Weather: 40, cloud coverage: 8. Wind: 310°, 17 kts. Sea: 3-5 ft. Wire angle: 01°.
BT slide: 206. Dry bulb: 58.9°F. Wet bulb: 57.2°F. Barometric pressure: 1019 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	14.80	33.31 2/	322.0	5.93	0.83
10	14.80	33.28	324.2	6.11	0.83
26	10.86	33.41 2/	241.0	6.58	1.00
63	8.60	33.79	177.5	6.30	1.32
116	7.42	33.77	162.3	6.26	1.32
234	7.07	33.87	150.2	5.38	1.48
354	5.49	33.95 2/	125.0	3.71	2.82
480	4.29	33.98 2/	109.9	2.81	3.17
600	4.00	34.18 2/	91.9	1.76	3.48
720	3.76	34.19	88.8	1.16	3.48
950	3.24	34.33	73.6	0.79	4.25
1179	2.86	34.39	65.8	0.68	4.25
1395	2.58	34.47	57.4	0.65	3.48

2/ Indicates H_2S precipitate in salinity sample.



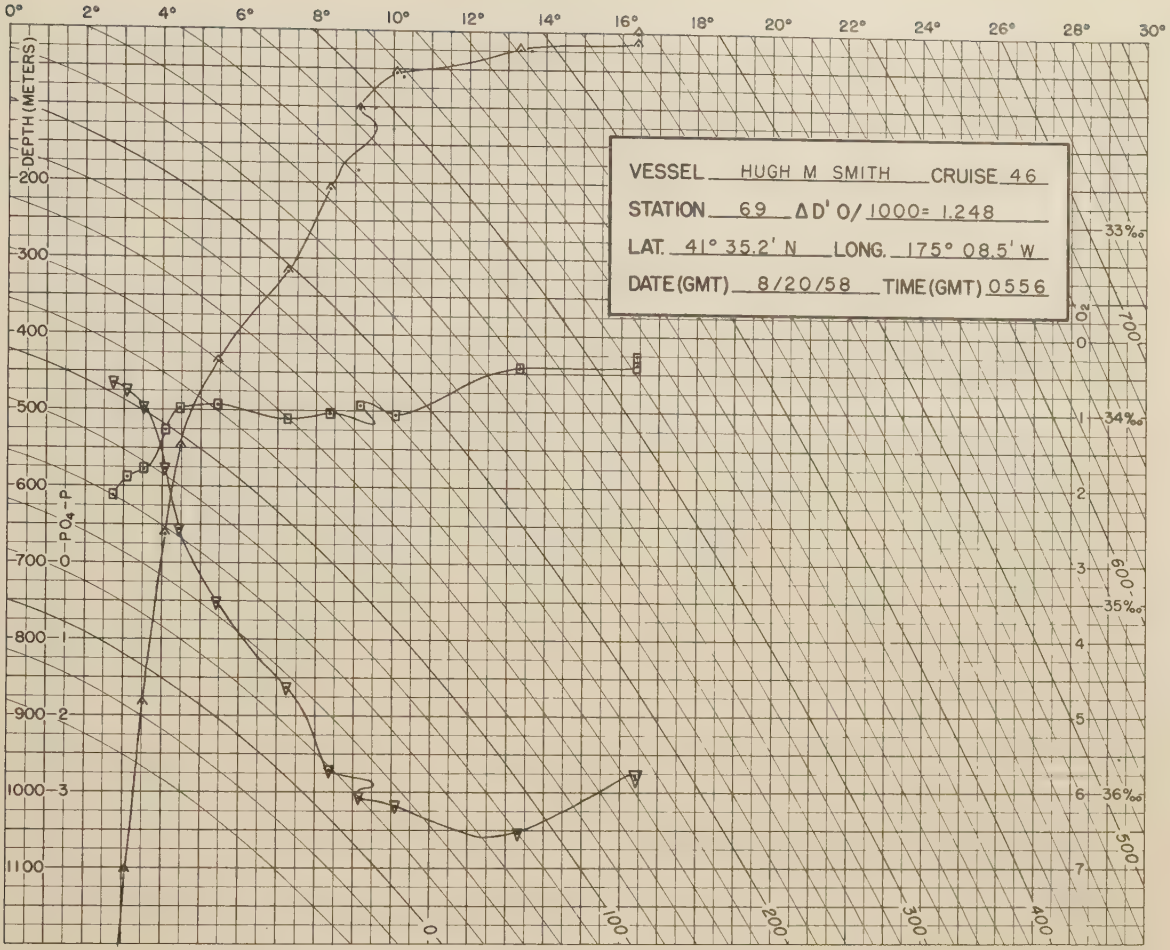
VESSEL HUGH M SMITH CRUISE 46
STATION 67 ΔD' 0/1000 = 1.217
LAT. 42° 47' N LONG. 175° 08' W
DATE (GMT) 8/18/58 TIME (GMT) 0529

POFI USFWS MAY 1956 T. NAKATA

Weather: 40, cloud coverage: 8. Wind: 290°, 18 kts. Sea: 3-5 ft. Wire angle: 29°. BT slide: 216. Dry bulb: 60.1°F. Wet bulb: 58.9°F. Barometric pressure: 1006 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	15.94	33.41	338.5	5.81	0.50
9	15.96	33.45	336.0	5.81	0.59
14	15.86	33.44	334.7	5.87	0.50
27	12.00	33.66 2/	242.7	6.72	0.70
50	9.98	33.98	184.8	6.17	1.00
99	8.97	34.01	166.5	5.93	1.32
199	7.63	33.88	157.1	5.94	1.16
300	6.89	33.99	139.1	4.73	1.91
406	5.22	33.95	121.9	3.47	2.63
613	3.98	34.07	100.0	1.70	3.32
821	3.56	34.25	82.6	0.94	3.64
1030	3.12	34.37	69.5	0.75	4.00
1231	2.80	34.43 2/	62.2	0.68	3.81

2/ Indicates H_2S precipitate in salinity sample.



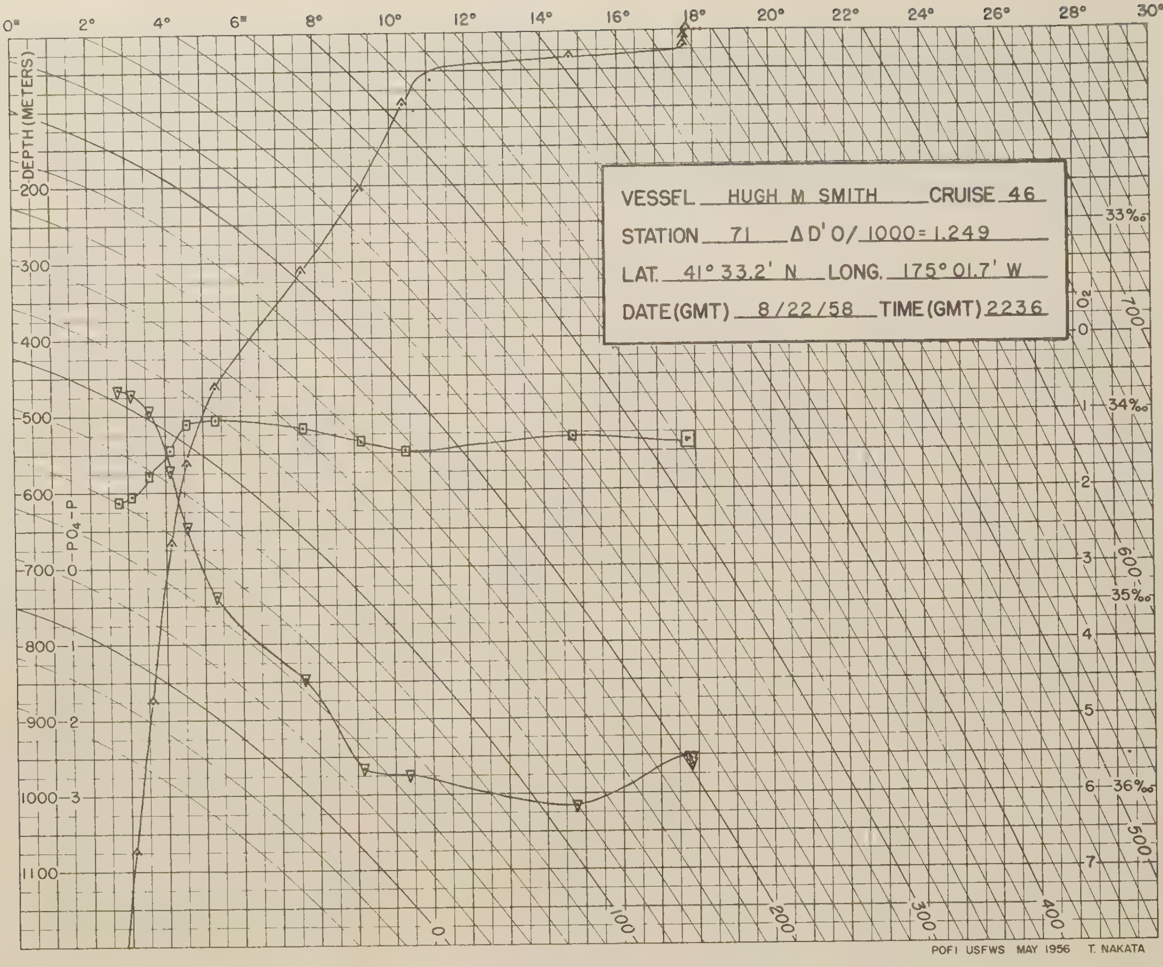
VESSEL HUGH M SMITH CRUISE 46
STATION 69 ΔD' 0/1000= 1.248
LAT. 41° 35.2' N LONG. 175° 08.5' W
DATE (GMT) 8/20/58 TIME (GMT) 0556

POFI USFWS MAY 1956 T NAKATA

Weather: 02, cloud coverage: 8. Wind: 360°, 18 kts. Sea: 5-8 ft. Wire angle: 27°. BT slide: 225. Dry bulb: 58.8°F. Wet bulb: 53.9°F. Barometric pressure: 1015 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	16.41	33.70	327.8	5.81	0.32
14	16.41	33.75 2/	324.0	5.78	0.00
23	13.32	33.77 2/	258.9	6.52	0.20
55	10.08	34.02 2/	183.2	6.18	0.50
102	9.14	33.97	172.3	6.07	0.50
209	8.36	34.01	157.6	5.71	1.00
318	7.25	34.04	139.9	4.61	1.32
435	5.43	33.97 2/	122.8	3.51	2.00
548	4.45	33.99	110.9	2.54	2.41
662	4.07	34.10	98.6	1.77	2.63
883	3.53	34.31 2/	77.8	0.95	2.82
1103	3.07	34.35	70.6	0.73	2.82
1310	2.72	34.45	60.1	0.64	3.48

2/ Indicates H_2S precipitate in salinity sample.

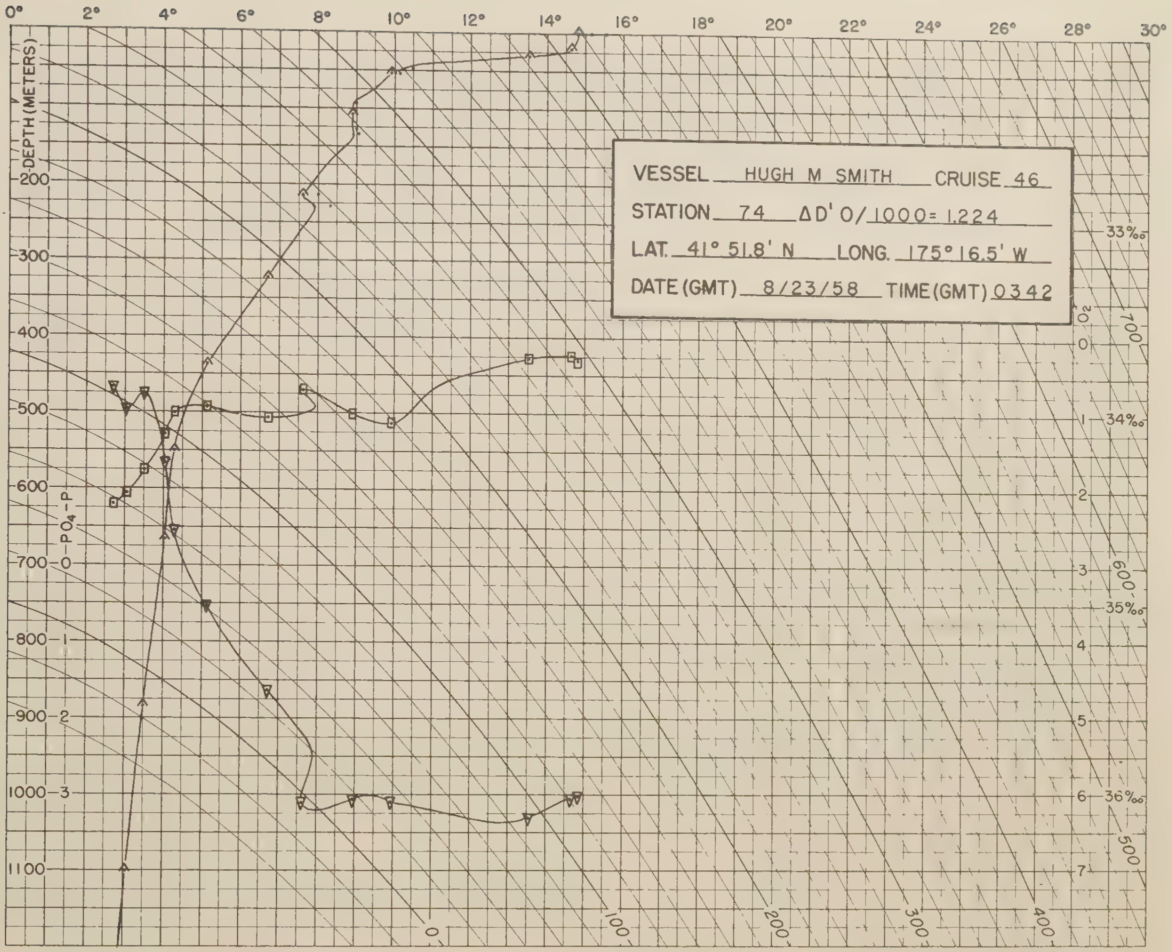


VESSEL HUGH M SMITH CRUISE 46
STATION 71 ΔD'0/1000=1.249
LAT. 41° 33.2' N LONG. 175° 01.7' W
DATE (GMT) 8/22/58 TIME (GMT) 2236

Weather: 02, cloud coverage: 7. Wind: calm, 0 kts. Sea: 1 ft. Wire angle: 22°. BT slide: 236. Dry bulb: 65.6°F. Wet bulb: 58.0°F. Barometric pressure: 1021 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	17.83	34.14	327.5	5.62	0.50
10	17.78	34.14	326.4	5.54	0.42
19	17.76	34.15	325.2	5.53	0.42
33	14.78	34.12	262.2	6.15	0.32
93	10.38	34.19 2/	175.7	5.73	0.83
206	9.16	34.14 2/	159.9	5.64	1.16
312	7.62	34.07	142.8	4.46	1.82
463	5.32	34.02 2/	117.8	3.36	2.62
563	4.57	34.04	108.2	2.45	3.00
668	4.14	34.18 2/	93.2	1.71	3.17
875	3.58	34.31	78.2	0.92	3.24
1075	3.11	34.42	65.6	0.70	3.81
1280	2.77	34.45	60.5	0.65	3.72

2/ Indicates H_2S precipitate in salinity sample.



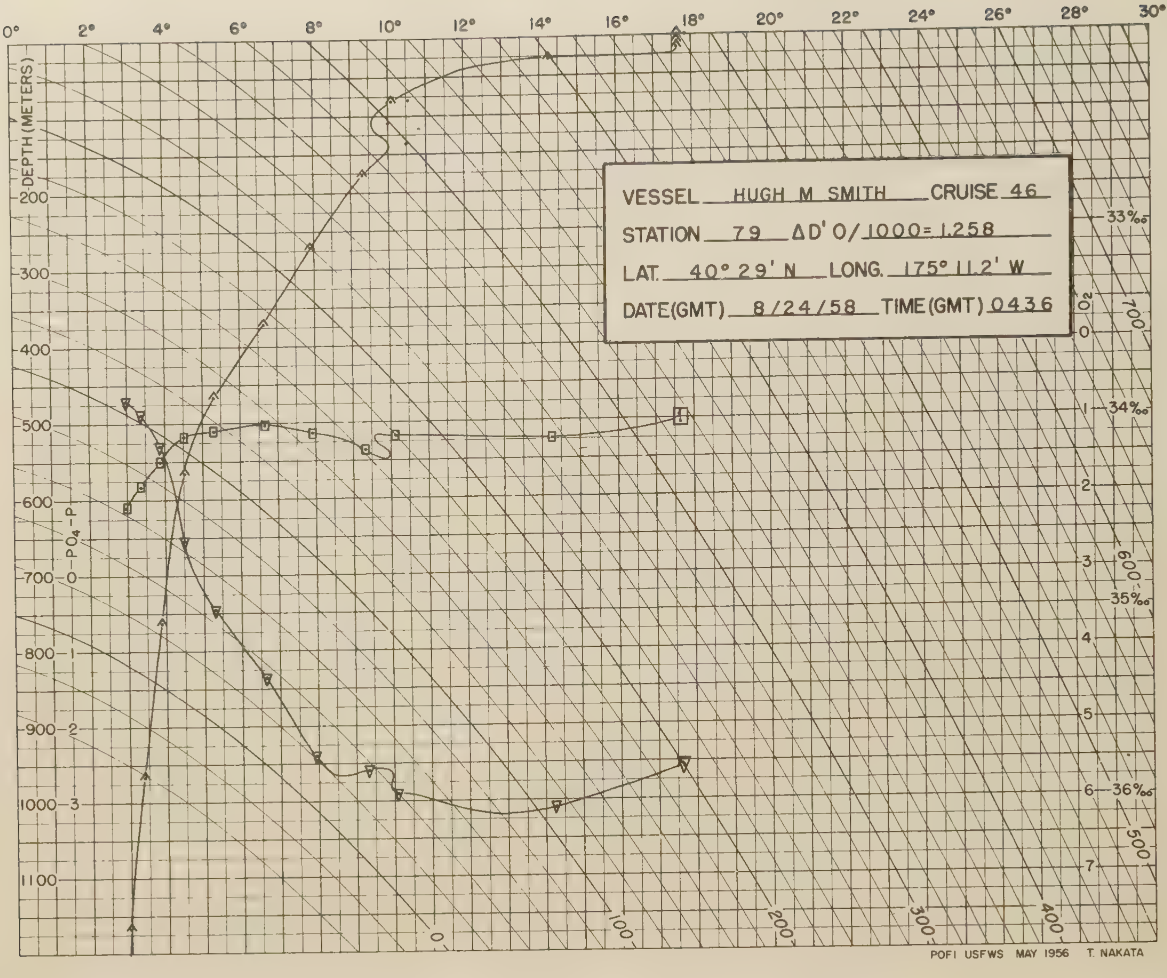
VESSEL HUGH M SMITH CRUISE 46
STATION 74 ΔD' 0/1000= 1.224
LAT. 41° 51.8' N LONG. 175° 16.5' W
DATE (GMT) 8/23/58 TIME (GMT) 0342

POFI USFWS MAY 1956 T NAKATA

Weather: 02, cloud coverage: 8. Wind: 030°, 03 kts. Sea: 1 ft. Wire angle: 22°.
BT slide: 240. Dry bulb: 62.0°F. Wet bulb: 55.8°F. Barometric pressure: 1019 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	14.83	33.72	292.5	6.01	0.64
20	14.65	33.69	291.1	6.04	0.83
30	13.54	33.71	267.5	6.30	0.59
54	9.93	34.05 2/	178.6	6.09	1.32
108	8.91	34.00	166.4	0.74 3/	0.59
214	7.61	33.88	157.0	6.10	1.24
322	6.71	34.02	134.3	4.63	2.30 P
437	5.14	33.97 2/	119.6	3.53	2.63
550	4.28	34.00	108.2	2.53	1.82 P
664	4.02	34.11 2/	97.4	1.66	3.32
883	3.48	34.30	78.0	6.06 3/	3.64
1100	3.04	34.42 2/	65.0	0.94	3.81
1305	2.73	34.48 2/	58.0	0.66	3.81

2/ Indicates H_2S precipitate in salinity sample.
3/ These two bottles may have been interchanged.

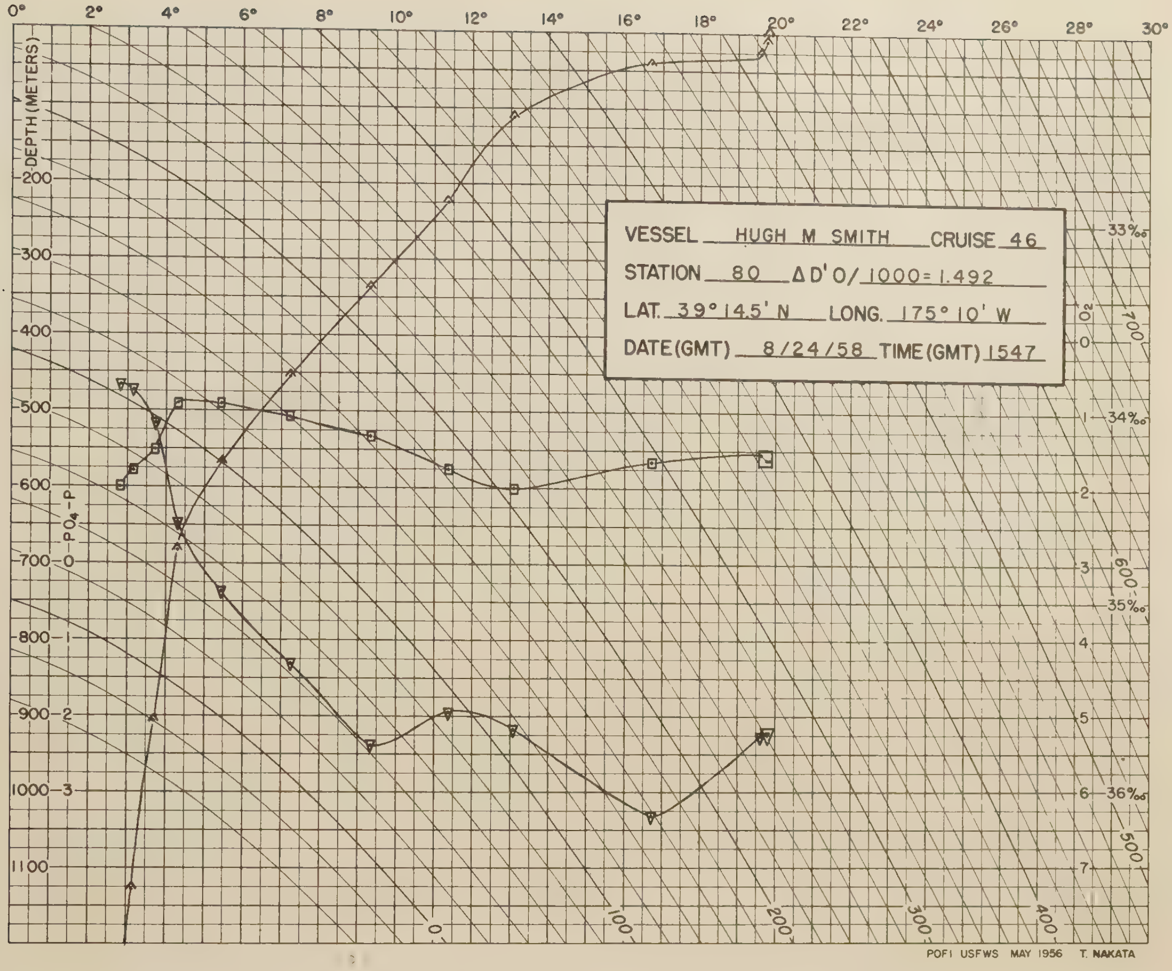


Weather: 53, cloud coverage: 9. Wind: 110°, 19 kts. Sea: 3-5 ft. Wire angle: 35°. BT slide: 247. Dry bulb: 62.3°F. Wet bulb: 60.5°F. Barometric pressure: 1018 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	17.62	34.02 2/	331.5	5.54	0.12
8	17.62	33.96	336.0	5.56	0.12
16	17.61	33.98	334.5	5.55	0.37
28	14.25	34.09 2/	253.8	6.10	0.26
81	10.10	34.07	179.8	5.90	0.64
179	9.34	34.14	162.7	5.59	0.91
271	7.91	34.05	148.2	5.39	1.08
370	6.63	34.01	134.1	4.34	1.56
466	5.30	34.04 2/	116.1	3.44	2.30
565	4.50	34.07	105.2	2.52	2.73
763	3.86	34.20	89.1	1.29	3.24
967	3.38	34.33	74.9	0.88	3.56
1168	2.98	34.44	62.9	0.70	3.72* 3.24

2/ Indicates H_2S precipitate in salinity sample.

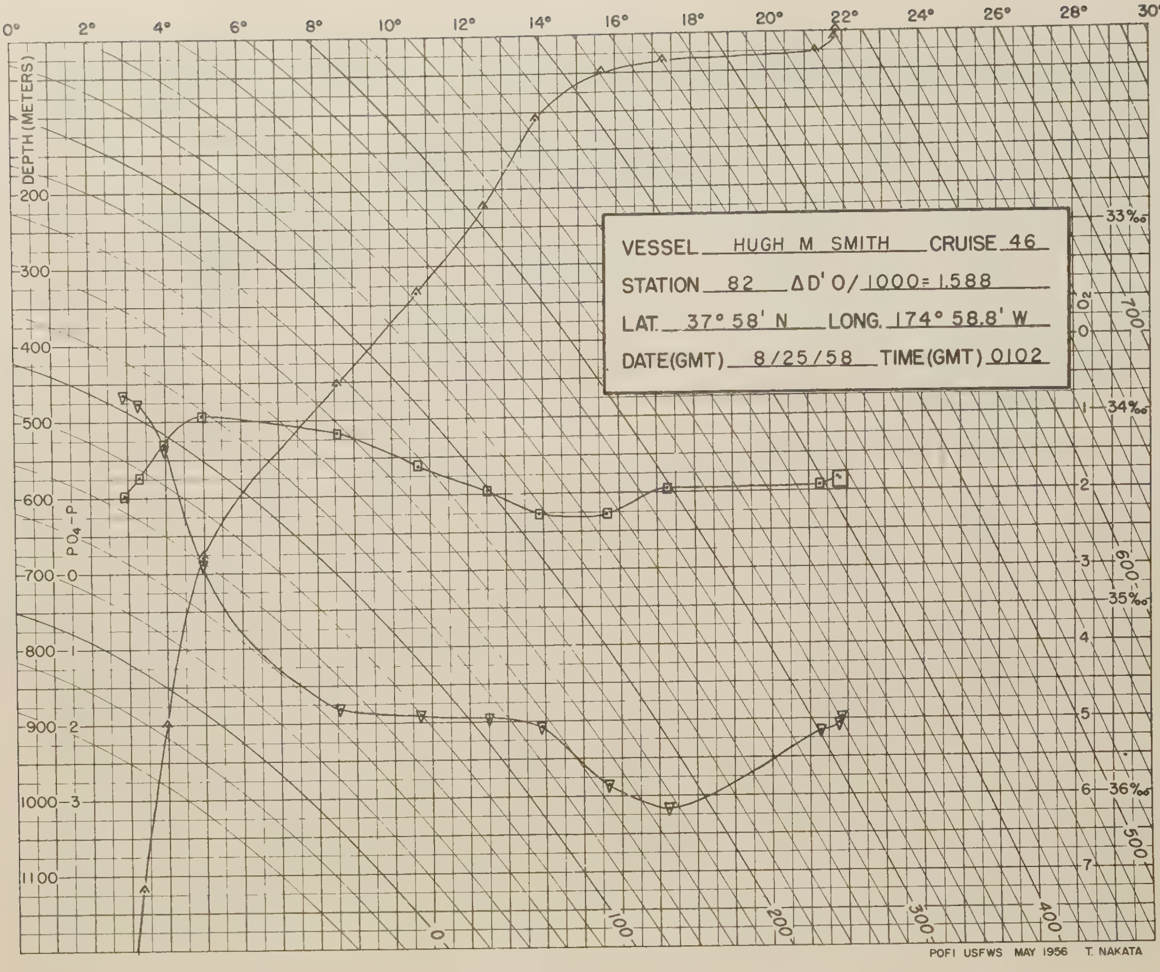
*Values of duplicate did not agree within 0.1 µg at./L. tolerance so both are carried.



VESSEL HUGH M SMITH CRUISE 46
STATION 80 ΔD'0/1000= 1.492
LAT. 39° 14.5' N LONG. 175° 10' W
DATE(GMT) 8/24/58 TIME(GMT) 1547

Weather: 00, cloud coverage: not recorded. Wind: 200°, 19 kts. Sea: 3-5 ft. Wire angle: 17°. BT slide: 252. Dry bulb: 70.3°F. Wet bulb: 69.3°F. Barometric pressure: 1013 mbs.

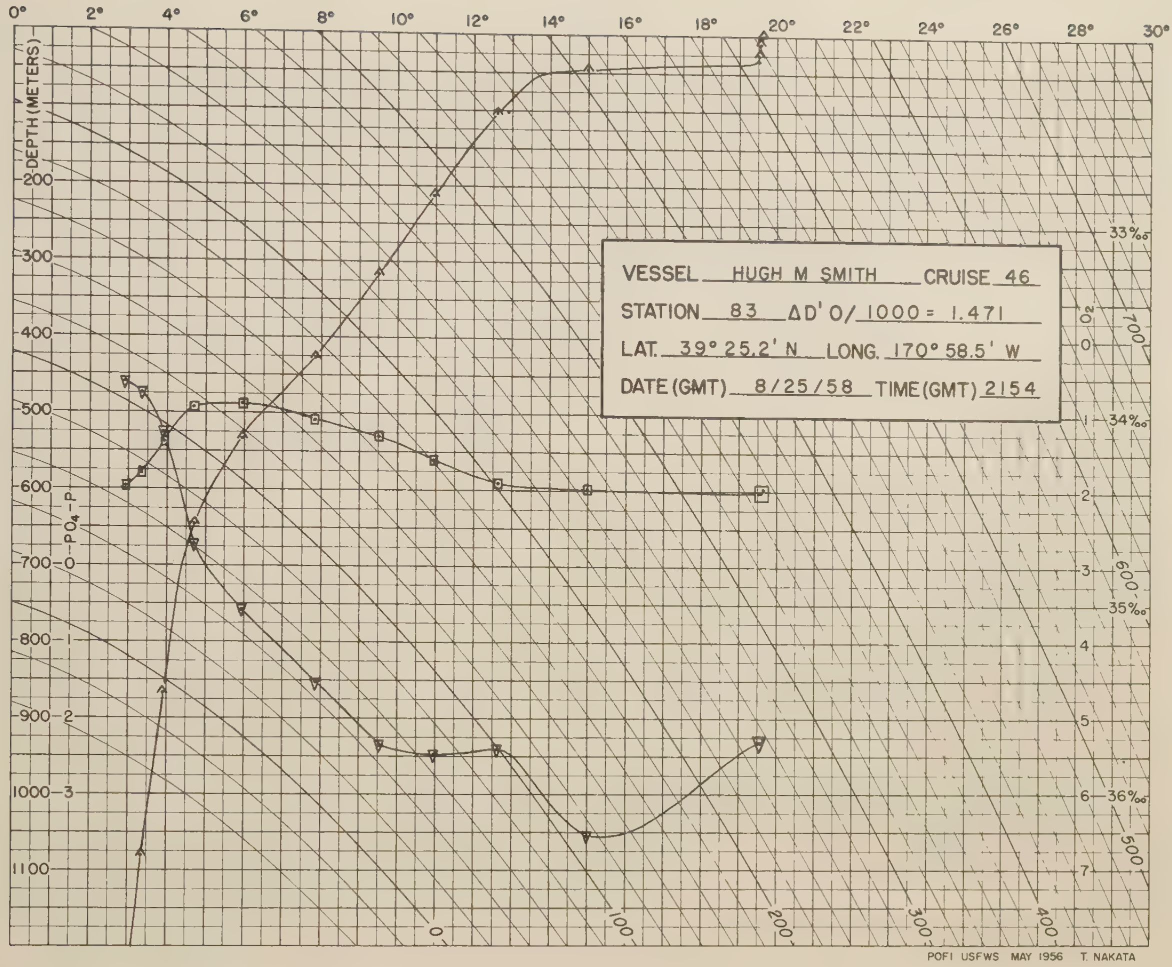
Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	19.80	34.25	367.0	5.22	0.00
10	19.77	34.25	366.3	5.22	0.20
25	19.62	34.22	364.8	5.26	0.20
40	16.70	34.26	293.3	6.31	0.20
112	13.06	34.40	207.7	5.18	0.83
224	11.37	34.30	184.3	4.94	1.16
336	9.34	34.13	163.4	5.38	1.32
454	7.23	34.03	140.3	4.31	1.82
568	5.44	33.96	123.6	3.36	2.19
682	4.31	33.96	111.7	2.46	3.17
906	3.72	34.20	87.8	1.16	3.48
1128	3.16	34.31	74.4	0.73	3.64
1337	2.82	34.40	64.7	0.66	3.81



VESSEL HUGH M SMITH CRUISE 46
STATION 82 ΔD' 0/1000= 1.588
LAT. 37° 58' N LONG. 174° 58.8' W
DATE(GMT) 8/25/58 TIME(GMT) 0102

Weather: 02, cloud coverage: 6. Wind: 210°, 22 kts. Sea: 3-5 ft. Wire angle: 16°. BT slide: 258. Dry bulb: 74.6°F. Wet bulb: 72.4°F. Barometric pressure: 1015 mbs.

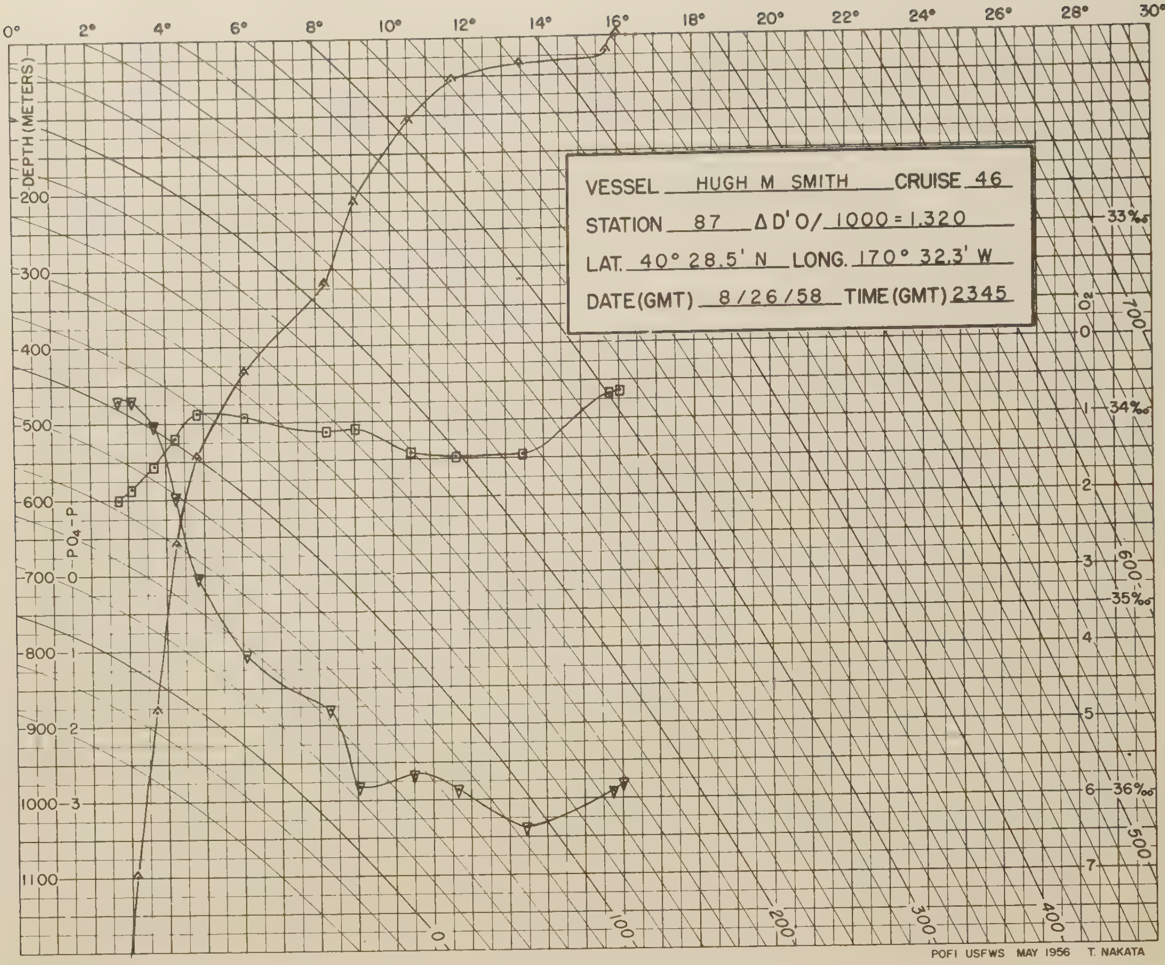
Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, μg at. /L.
0	21.82	34.34	412.3	4.98	0.20
10	21.76	34.33	411.4	5.05	0.20
25	21.28	34.37	396.1	5.16	0.00
35	17.24	34.38	296.6	6.17	0.00
50	15.65	34.51	252.1	5.85	0.00
110	13.88q	34.50	216.3	5.07	0.42
222	12.51	34.38	198.9	4.94	0.70
334	10.71	34.25	176.7	4.90	1.00
453	8.56	34.07	156.1	4.80	1.40
679	4.95	33.97	117.4	2.88	2.73
900	3.96	34.12	96.1	1.33	3.17
1119	3.30	34.29	77.2	0.76	3.64
1328	2.89	34.39	66.0	0.64	3.81



VESSEL HUGH M SMITH CRUISE 46
STATION 83 ΔD' 0/1000 = 1.471
LAT. 39° 25.2' N LONG. 170° 58.5' W
DATE (GMT) 8/25/58 TIME (GMT) 2154

Weather: 02, cloud coverage: 8. Wind: 220°, 15 kts. Sea: 1-3 ft. Wire angle: 12°.
BT slide: 264. Dry bulb: 72.0°F. Wet bulb: 68.2°F. Barometric pressure: 1015 mbs.

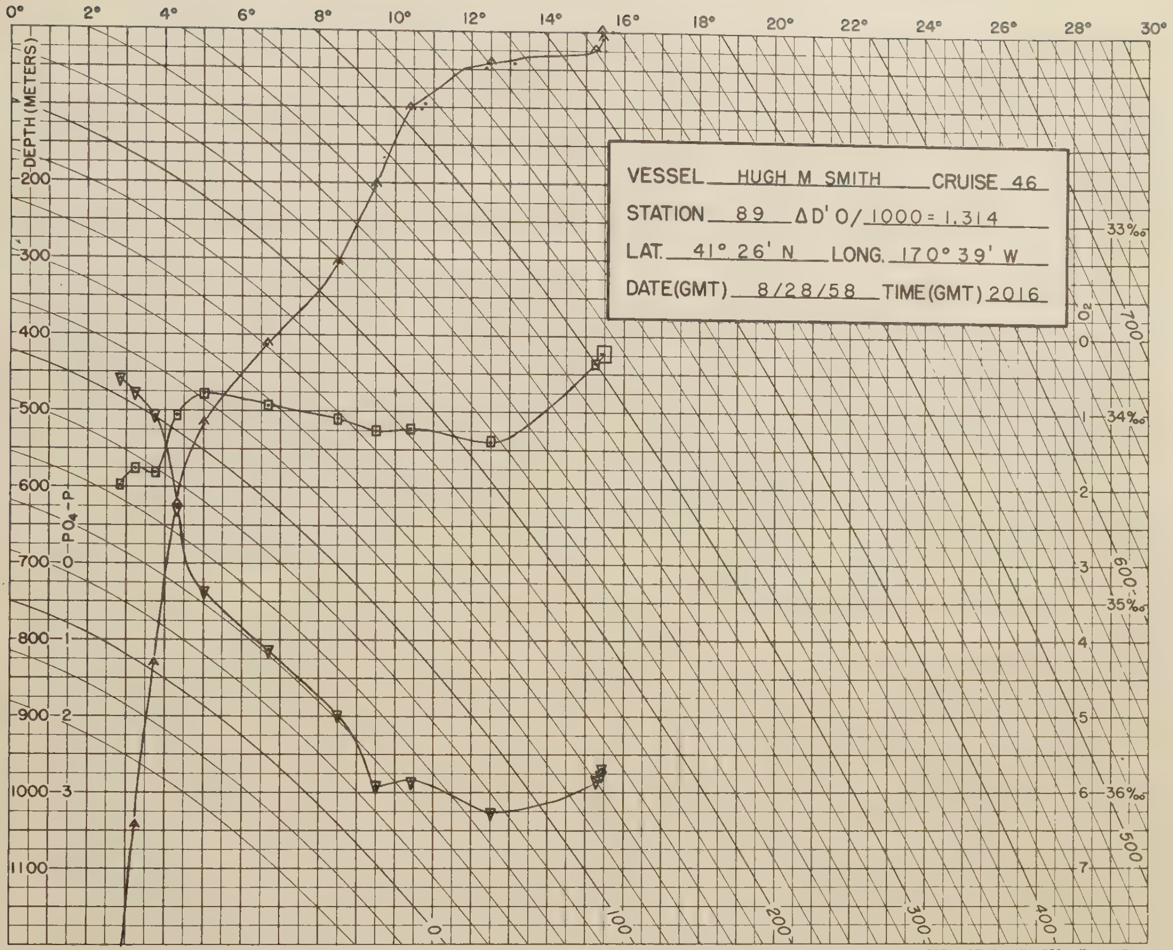
Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	19.64	34.39	352.8	5.25	0.00
10	19.58	34.41	350.0	5.31	0.00
26	19.54	34.41	349.1	5.31	0.00
46	14.98	34.39	246.8	6.55	0.00
103	12.62	34.36	201.4	5.40	0.50
212	10.95	34.24	181.3	5.47	0.70
316	9.54	34.12	167.4	5.34	0.70
427	7.85	34.03	148.9	4.52	1.08
533	5.94	33.95	130.1	3.58	1.48
646	4.71	33.97	114.9	2.70	1.82
867	3.90	34.15	93.2	1.25	2.63
1080	3.35	34.31	76.2	0.73	2.63
1292	2.91	34.38	67.0	0.59	3.00



VESSEL HUGH M SMITH CRUISE 46
STATION 87 ΔD'0/1000 = 1.320
LAT. 40° 28.5' N LONG. 170° 32.3' W
DATE (GMT) 8/26/58 TIME (GMT) 2345

Weather: 47, cloud coverage: 9. Wind: 200°, 19 kts. Sea: 1-3 ft. Wire angle: 22°.
BT slide: 272. Dry bulb: 65.0°F. Wet bulb: 64.7°F. Barometric pressure: 1015 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O_2, ml./L.	PO_4-P, µg at./L.
0	16.02	33.85	308.1	5.81	0.20
20	15.75	33.87	301.1	5.90	0.00
35	13.44	34.18	231.3	6.37	0.32
55	11.66	34.19	197.5	5.87	0.42
108	10.52	34.17	179.4	5.65	0.70
214	9.03	34.04	165.3	5.81	0.83
320	8.26	34.05	153.2	4.78	1.32
434	6.08	33.97	130.4	4.05	2.20
546	4.84	33.95	117.9	3.02	3.00
659	4.26	34.08	102.0	1.97	3.00
880	3.69	34.22	86.0	1.02	3.32
1099	3.14	34.34	72.0	0.70	3.48
1307	2.77	34.40	64.2	0.70	3.32

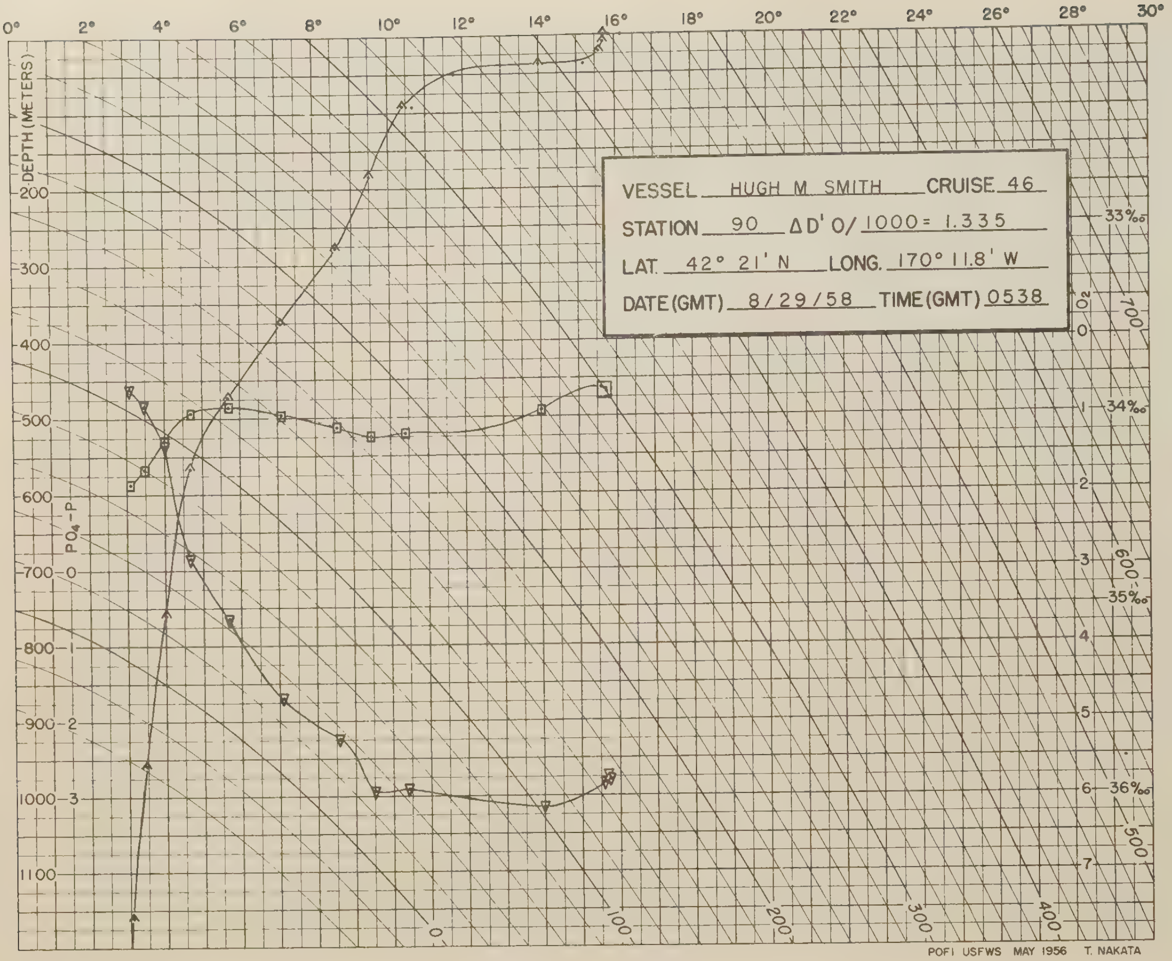


VESSEL HUGH M SMITH CRUISE 46
STATION 89 ΔD'0/1000 = 1.314
LAT. 41° 26' N LONG. 170° 39' W
DATE(GMT) 8/28/58 TIME(GMT) 2016

POFI USFWS MAY 1956 T NAKATA

Weather: 02, cloud coverage: 9. Wind: not recorded, 12 kts. Sea: 5-8 ft. Wire angle: 30°. BT slide: 284. Dry bulb: 61.4°F. Wet bulb: 58.6°F. Barometric pressure: 1018 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O_2, ml. /L.	PO_4-P, µg at. /L.
0	15.42	33.69	307.0	5.76	0.70
9	15.44	33.69	307.5	5.69	0.70
23	15.26	33.74	299.9	5.84	0.59
42	12.51	34.16	215.0	6.27	0.83
102	10.40	34.09	183.4	5.84	1.16
203	9.49	34.10	167.9	5.91	1.16
306	8.51	34.04	157.8	4.99	1.64
413	6.67	33.97	137.7	4.12	1.82
518	5.00	33.91	122.4	3.36	2.00
623	4.33	34.02	107.2	2.27	2.82
832	3.74	34.32	78.9	1.07	3.00
1044	3.22	34.30	75.7	0.76	3.17
1248	2.84	34.39	65.7	0.58	2.82



VESSEL HUGH M. SMITH CRUISE 46

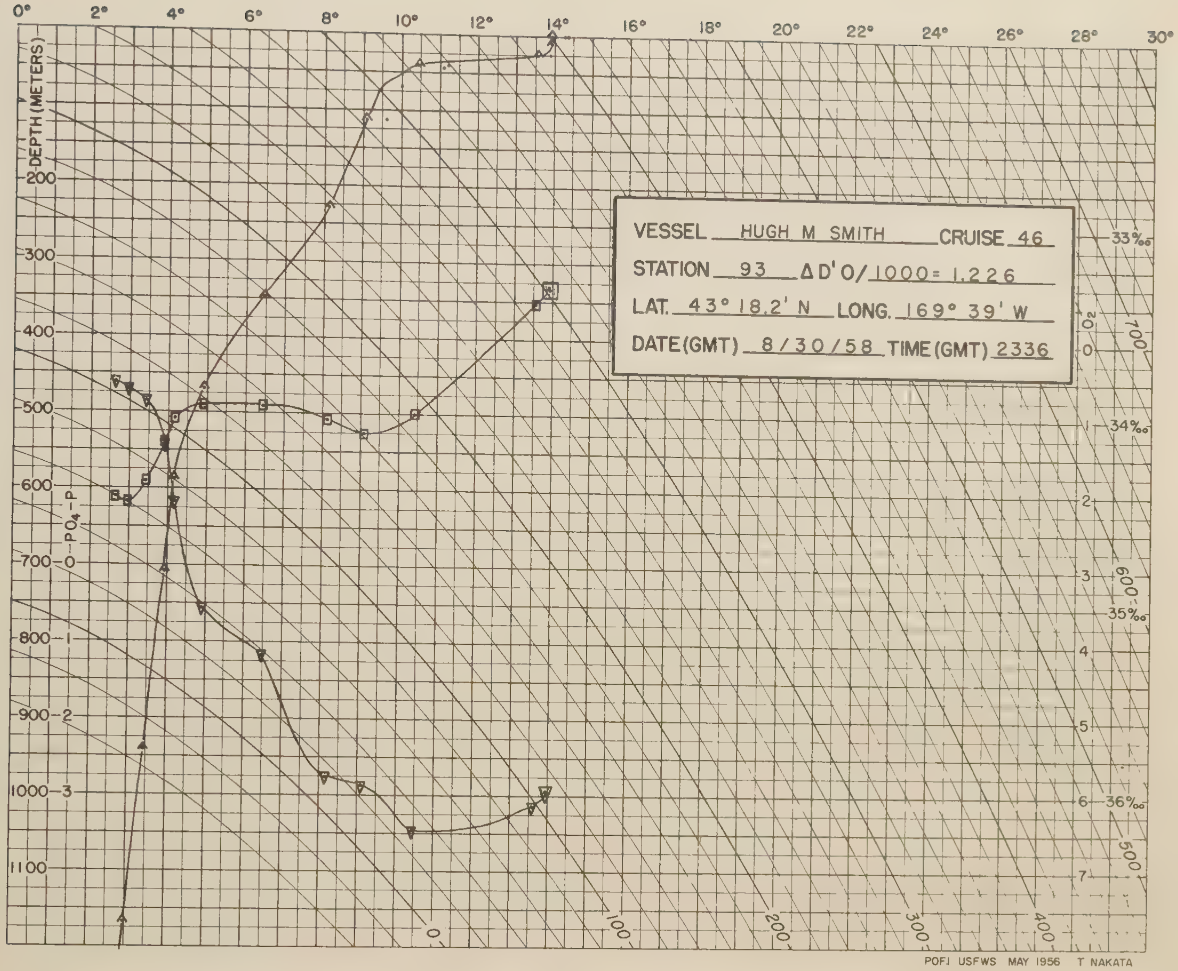
STATION 90 ΔD' 0/1000 = 1.335

LAT. 42° 21' N LONG. 170° 11.8' W

DATE (GMT) 8/29/58 TIME (GMT) 0538

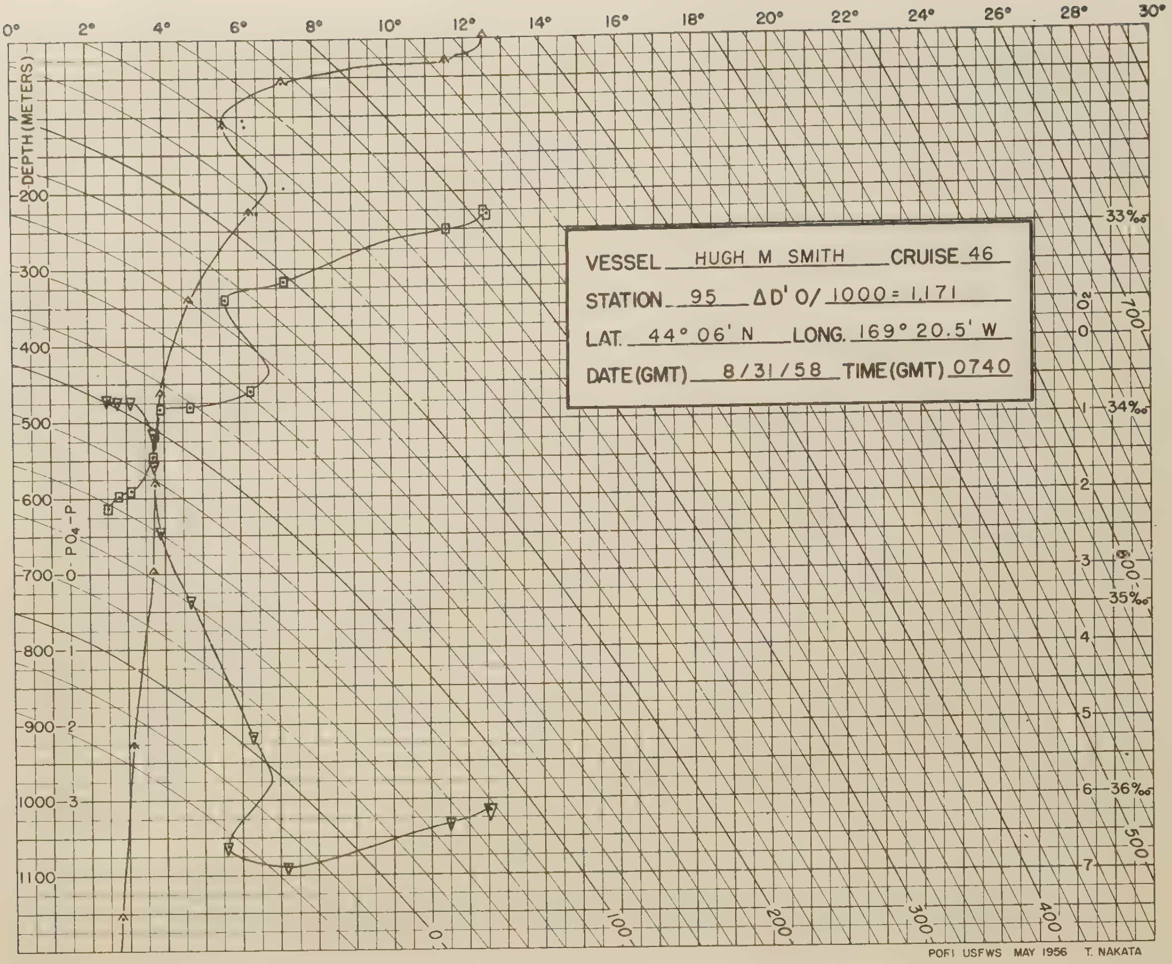
Weather: 01, cloud coverage: 6. Wind: 270°, 04 kts. Sea: 1-3 ft. Wire angle: 33°.
BT slide: 287. Dry bulb: 60.0°F. Wet bulb: 58.2°F. Barometric pressure: 1019 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	15.73	33.87	300.8	5.78	0.70
9	15.71	33.86	301.0	5.72	0.70
21	15.60	33.85	299.2	5.81	0.70
38	14.00	33.96	258.3	6.14	0.76
92	10.40	34.08	184.1	5.90	1.16
184	9.49	34.10	168.0	5.92	1.32
278	8.58	34.05	157.9	5.22	1.32
376	7.07	33.98	142.1	4.69	1.73
472	5.68	33.94	127.8	3.64	2.52
567	4.67	33.97	114.6	2.84	2.73
759	4.00	34.12	96.5	1.36	3.00
959	3.46	34.27	80.1	0.83	3.24
1160	3.08	34.35	70.6	0.60	3.24


VESSEL HUGH M SMITH CRUISE 46
STATION 93 ΔD'0/1000= 1.226
LAT. 43° 18.2' N LONG. 169° 39' W
DATE(GMT) 8/30/58 TIME(GMT) 2336

Weather: 02, cloud coverage: 6. Wind: 080°, 18 kts. Sea: 1-3 ft. Wire angle: 12°. BT slide: 295. Dry bulb: 57.7°F. Wet bulb: 54.7°F. Barometric pressure: 1025 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	13.92	33.32	303.8	5.93	0.59
10	13.94	33.33	303.3	5.97	0.59
26	13.57	33.41	290.2	6.12	0.59
41	10.44	34.00	190.5	6.46	0.64
113	9.08	34.10	161.6	5.86	0.91
229	8.14	34.03	153.0	5.76	1.08
346	6.45	33.96	135.7	4.17	1.56
469	4.91	33.96	117.9	3.55	2.00
588	4.18	34.03	105.0	2.17	2.30
708	3.91	34.16	92.6	1.44	2.63
940	3.42	34.36	73.0	0.85	2.63
1168	2.96	34.47	60.5	0.70	2.73
1382	2.64	34.44	60.2	0.60	2.92



VESSEL HUGH M SMITH CRUISE 46

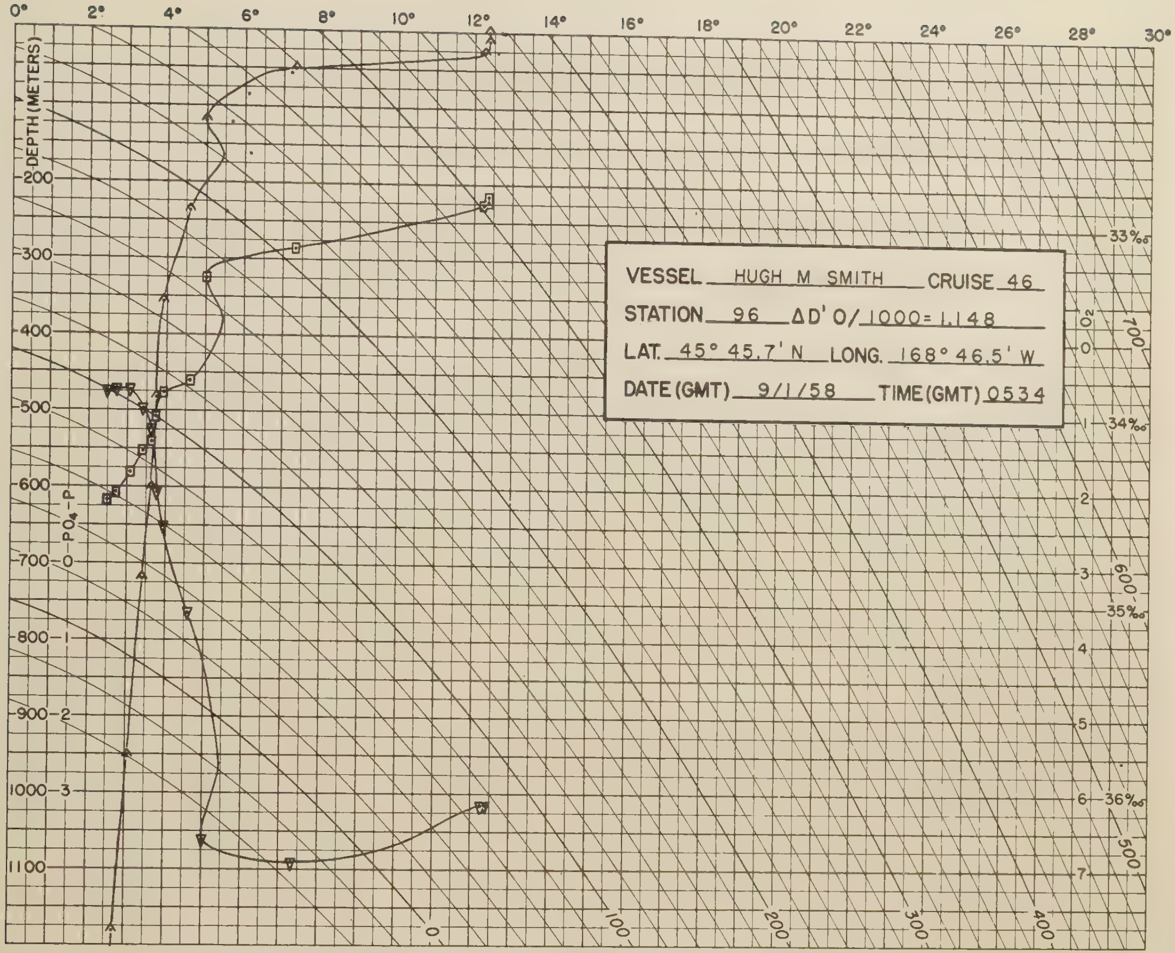
STATION 95 ΔD' 0/ 1000 = 1.171

LAT. 44° 06' N LONG. 169° 20.5' W

DATE (GMT) 8/31/58 TIME (GMT) 0740

Weather: 50, cloud coverage: 9. Wind: 100°, 18 kts. Sea: 3-5 ft. Wire angle: 15°. BT slide: 299. Dry bulb: 56.5°F. Wet bulb: 55.1°F. Barometric pressure: 1023 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	12.51	32.90	307.8	6.12	0.83
10	12.58 P	32.92	307.5	6.15	0.83
31	11.50	33.00	282.2	6.32	0.83
57	7.18	33.27	196.4	6.89	1.00
113	5.61	33.36	170.5	6.61	1.16
227	6.29	33.84	142.7	5.14	1.48
342	4.68	33.92	118.6	3.36	1.82
464	3.88	33.93	109.8	2.44	2.20
582	3.74	34.07	97.7	1.57	2.30
699	3.67	34.18	88.8	1.16	2.42
928	3.12	34.36	70.3	0.73	2.91
1155	2.79	34.39	65.2	0.73	3.00
1367	2.51	34.45	58.4	0.71	3.00



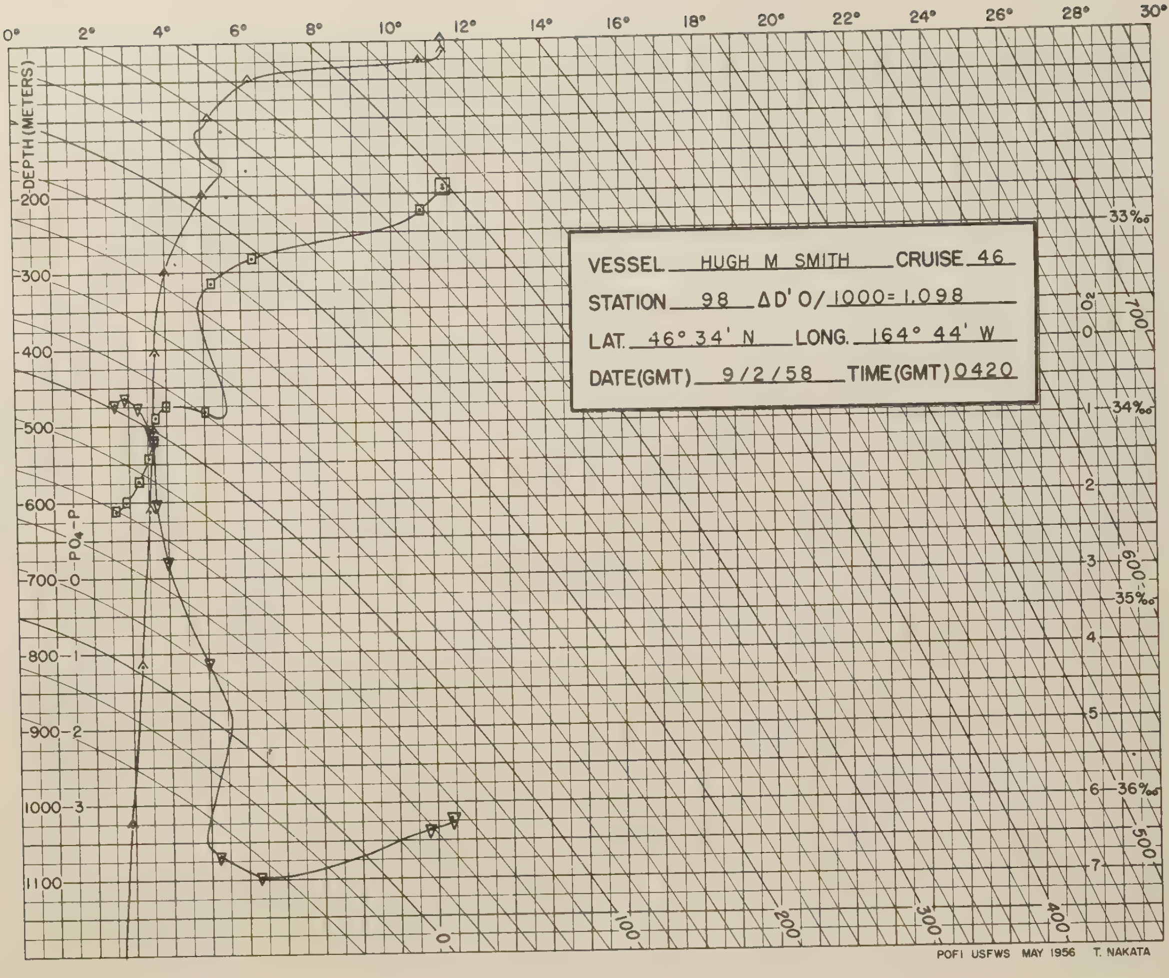
VESSEL HUGH M SMITH CRUISE 46
STATION 96 ΔD' 0/1000=1.148
LAT. 45° 45.7' N LONG. 168° 46.5' W
DATE (GMT) 9/1/58 TIME (GMT) 0534

POFI USFWS MAY 1956 T. NAKATA

Weather: 55, cloud coverage: 9. Wind: 160°, 13 kts. Sea: 1-3 ft. Wire angle: 04°.
BT slide: 306. Dry bulb: 58.3°F. Wet bulb: 58.0°F. Barometric pressure: 1008 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	12.38	32.86	308.2	6.15	1.16
12	12.38	32.89	306.1	6.14	1.00
28	12.26	32.91	302.3	6.15	1.00
50	7.32	33.14	207.9	6.90	1.16
119	5.00	33.30	168.2	6.61	1.32
237	4.60	33.84	123.6	3.64	1.82
357	3.92	33.90	112.2	2.51	2.20
482	3.75	34.03	100.9	2.06	2.41
602	3.61	34.16 2/	89.8	1.22	1.82 P
720	3.41	34.21	84.2	0.98	2.82
953	3.06	34.32	72.7	0.73	3.00
1181	2.72	34.43	61.7	0.71	3.00
1395	2.48	34.47	56.6	0.76	2.91

2/ Indicates H_2S precipitate in salinity sample.



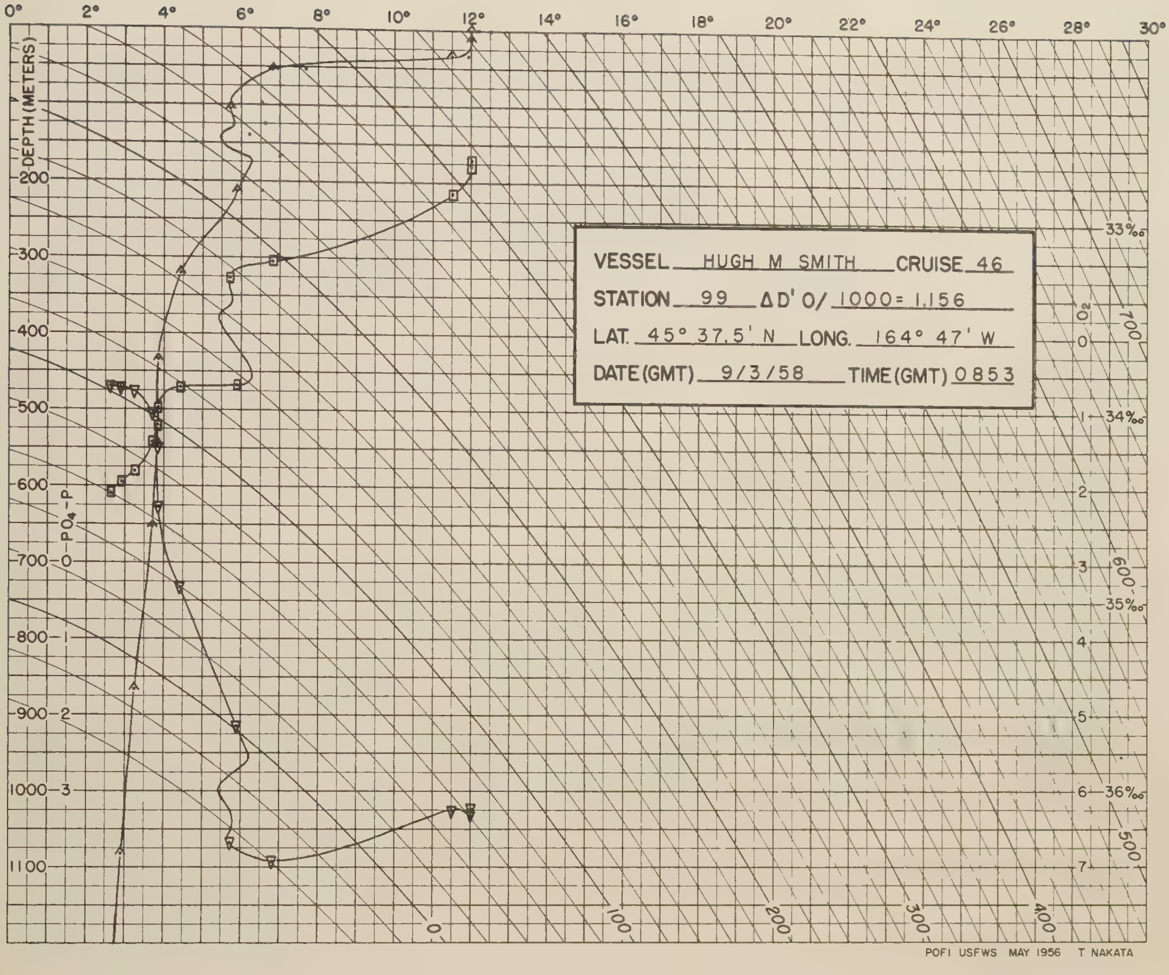
VESSEL HUGH M SMITH CRUISE 46
STATION 98 ΔD' 0/1000=1.098
LAT. 46° 34' N LONG. 164° 44' W
DATE(GMT) 9/2/58 TIME(GMT) 0420

POFI USFWS MAY 1956 T. NAKATA

Weather: 45, cloud coverage: 9. Wind: 240°, 14 kts. Sea: 3-5 ft. Wire angle: 27°. BT slide: 312. Dry bulb: 55.0°F. Wet bulb: 55.0°F. Barometric pressure: 1009 mbs.

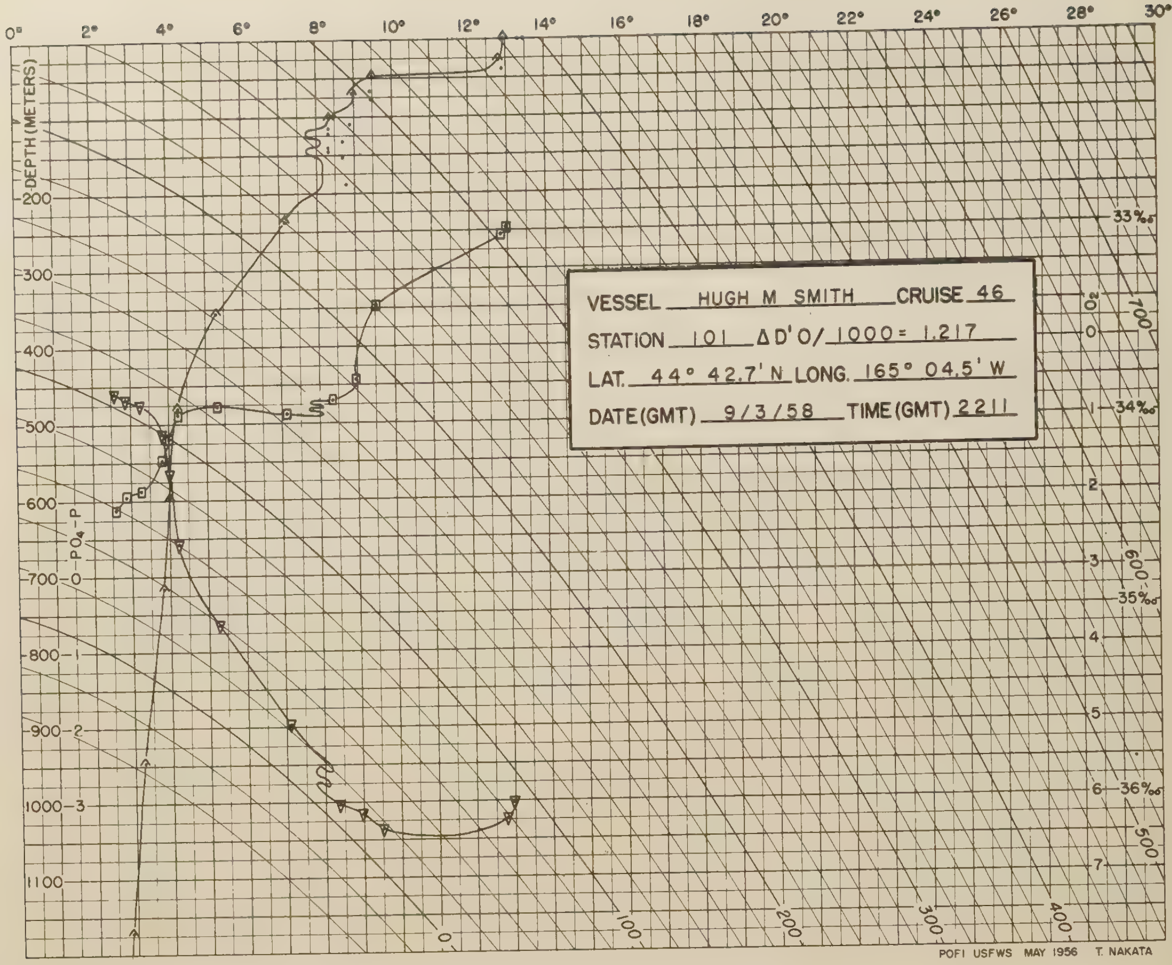
Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	11.38	32.76	297.8	6.21	1.32
14	11.40	32.77	297.3	6.26	1.32
28	10.80	32.89	278.4	6.36	1.32
50	6.32	33.13	196.2	6.98	1.32
100	5.22	33.26 2/	173.6	6.69	1.49
201	5.01	33.93 Q	121.1	4.13 Q	2.30
301	3.99	33.90	112.9	2.78	1.82
407	3.72	33.96	105.8	2.01	2.10
509	3.64	34.08	96.1	1.22	2.82
612	3.52	34.17	88.3	1.04	2.41
816	3.24	34.29	76.7	0.75	3.00
1027	2.89	34.40	65.3	0.63	2.82
1231	2.63	34.45	59.4	0.71	2.14

2/ Indicates H_2S precipitate in salinity sample.



Weather: 65, cloud coverage: 9. Wind: 230°, 22 kts. Sea: 3-5 ft. Wire angle: 25°. BT slide: 319. Dry bulb: 55.8°F. Wet bulb: 55.0°F. Barometric pressure: 1012 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl. /ton	O2, ml. /L.	PO4-P, µg at. /L.
0	12.01	32.68	314.9	6.23	1.16
14	12.00	32.71	312.4	6.32	0.70
34	11.52	32.86	292.9	6.24	1.00
53	6.82	33.22	195.4	6.92	1.08
106	5.71	33.31	175.3	6.68	1.32
213	5.88	33.87	135.3	5.13	1.48
321	4.43	33.88	119.0	3.32	1.82
434	3.85	33.99	104.8	2.27	2.20
543	3.82	34.08	97.8	1.49	2.30
652	3.70	34.17	89.8	1.04	2.73
866	3.24	34.32	74.4	0.75	2.82
1081	2.89	34.38	66.7	0.71	2.82
1286	2.63	34.44	60.2	0.69	2.91



VESSEL HUGH M SMITH CRUISE 46

STATION 101 ΔD'0/1000 = 1.217

LAT. 44° 42.7' N LONG. 165° 04.5' W

DATE (GMT) 9/3/58 TIME (GMT) 2211

POFI USFWS MAY 1956 T. NAKATA

Weather: 01, cloud coverage: 6. Wind: 200°, 22 kts. Sea: 5-8 ft. Wire angle: 05°. BT slide: 323. Dry bulb: 61.5°F. Wet bulb: 58.5°F. Barometric pressure: 1008 mbs.

Depth, m.	T, °C.	S, °/oo	δ t, cl./ton	O2, ml./L.	PO4-P, µg at./L.
0	12.94	32.98	309.8	6.02	1.00
27	12.81	33.02	304.5	6.23	1.00
48	9.52	33.39	220.9	6.35	1.32
70	8.96	33.77	184.2	6.15	1.32
102	8.35	33.88	167.1	6.02	1.48
237	7.10	33.95	144.8	4.97	1.48
356	5.27	33.91	125.3	3.64	1.56
480	4.25	33.95	111.8	2.57	2.82
598	4.00	34.08	99.5	1.65	1.82
717	3.81	34.19	89.4	1.13	3.17
946	3.25	34.35	72.2	0.75	3.00
1171	2.86	34.38	66.5	0.68	3.17
1382	2.59	34.45	59.1	0.60	3.09

Table 14.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Baro-meter, (mb.)	Wea-ther	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T)	Force, (kt)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
1	0450	7/22	21°11'	158°19'	79.0	12	18	77.2	71.0	1016	02	8,2	2	9	2	10	2	
2	0625	7/22	21°11'	158°19'	78.9	12	18	79.4	72.8	1016	02	8,2	2	9	2	10	2	
3	0717	7/22	21°11'	158°19'	78.8	13	12	77.0	71.2	1017	00	-	-	9	2	--	-	
4	0810	7/22	21°11'	158°19'	79.0	13	14	77.8	70.3	1017	00	-	-	9	2	--	-	
5	0940	7/22	21°11'	158°19'	78.9	01	09	76.8	70.8	1017	00	-	-	9	2	--	-	
6	1040	7/22	21°11'	158°19'	78.7	02	09	77.8	71.2	1017	00	-	-	9	2	--	-	
7	1150	7/22	21°11'	158°19'	78.6	08	12	77.2	70.9	1017	00	-	-	9	2	--	-	
8	1305	7/22	21°11'	158°19'	78.6	08	12	77.2	70.9	1017	00	-	-	9	2	--	-	
9	1500	7/22	21°34'	158°25'	78.8	--	--	76.8	70.0	1017	00	-	-	9	2	--	-	
10	1800	7/22	22°02'	158°28'	77.9	07	15	76.7	71.8	1018	50	0,7	9	7	3	06	1	
11	2100	7/22	22°30'	158°30'	77.5	07	15	79.5	72.5	1018	02	2,8	2	9	3	07	1	
12	2400	7/22	22°59'	158°31'	78.4	07	15	78.8	72.1	1018	02	2,8	2	9	3	06	1	
13	0300	7/23	23°25'	158°32'	77.9	07	15	79.5	72.2	1018	02	8	1	9	3	06	1	
14	0540	7/23	23°55'	158°32'	77.4	06	18	76.1	70.6	1018	02	8	5	9	3	05	2	
15	0725	7/23	23°56'	158°33'	77.7	06	16	76.2	70.8	1019	02	x	x	9	3	05	1	
16	1200	7/23	24°33'	158°30'	77.3	07	15	75.2	70.6	1019	02	x	x	9	3	xx	x	
17	1500	7/23	25°03'	158°32'	76.8	06	11	74.9	71.0	1016	00	x	x	9	3	xx	x	
18	1730	7/23	25°28'	158°34'	75.4	05	10	73.0	69.7	1020	03	7,8	6	7	3	06	1	
19	1915	7/23	25°34'	158°34'	75.6	06	10	76.8	71.9	1020	51	8	9	7	2	xx	x	
20	2235	7/23	26°06'	158°37'	75.6	07	14	76.8	71.4	1017	02	8	4	9	2	07	3	
21	0200	7/24	26°32'	158°38'	76.4	08	15	78.7	71.2	1019	01	4,8	3	9	2	05	2	
22	0545	7/24	27°07'	158°38'	74.8	07	14	75.3	69.8	1020	02	8	2	9	3	06	1	
23	0645	7/24	27°08'	158°38'	75.0	07	14	75.3	69.8	1020	02	8	2	9	3	06	1	
24	1130	7/24	27°44'	158°36'	75.5	07	12	74.8	69.7	1020	00	x	x	9	3	07	1	
25	1500	7/24	28°18'	158°40'	74.8	09	15	74.2	69.6	1019	01	6	2	9	2	xx	x	
26	1750	7/24	28°45'	158°44'	74.3	10	10	75.9	70.0	1021	02	8	4	9	2	12	1	
27	1900	7/24	28°47'	158°44'	74.2	10	10	75.9	70.0	1021	02	8	4	9	2	12	1	
28	2245	7/24	29°28'	158°51'	74.8	11	07	77.0	69.5	1021	02	6	6	9	2	12	1	
29	0240	7/25	30°02'	158°54'	76.0	12	10	77.8	70.0	1019	02	5	2	9	2	12	1	
30	0600	7/25	30°34'	158°56'	75.5	12	10	75.8	67.6	1020	02	6	2	9	2	12	1	
31	0710	7/25	30°36'	158°56'	75.5	12	11	75.1	68.5	1020	02	6	2	92	2	12	1	
32	1220	7/25	31°06'	158°52'	74.7	16	10	74.3	69.1	1019	00	x	x	9	2	xx	x	
33	1600	7/25	31°53'	158°52'	74.0	26	07	74.5	69.0	1018	01	4	1	9	1	26	1	
34	1900	7/25	32°25'	158°50'	74.5	19	13	75.0	69.1	1018	02	4,8	4	9	2	15	1	
35	2015	7/25	32°27'	158°51'	75.3	18	14	75.0	69.1	1018	02	4,8	4	9	2	15	1	
36	2345	7/25	33°03'	158°50'	75.4	19	17	77.0	71.5	1017	02	4,8	3	9	2	15	1	
37	0330	7/26	33°34'	158°51'	75.3	19	14	75.9	71.0		02	8,4	3	9	2	18	1	
38	0650	7/26	34°01'	158°54'	74.7	18	20	75.2	71.2	1016	00	x	x	9	3	xx	x	
39	0755	7/26	34°03'	158°54'	74.7	18	20	75.2	71.2	1016	00	x	x	9	3	xx	x	
40	1230	7/26	34°36'	158°56'	73.3	18	20	74.0	70.9	1015	02	x	x	9	3	21	1	

Table 14.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46 (cont'd)

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Baro- meter (mb.)	Wea- ther	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T.)	Force (kt.)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
41	1600	7/26	35°12'	158°57'	73.8	21	20	73.8	71.7	1015	50	7	8	7	4	21	1	34.23
42	1915	7/26	35°44'	158°58'	73.0	02	11	75.0	70.4	1015	21	4,5	5	9	4	21	1	
43	2015	7/26	35°46'	158°58'	73.2	02	13	74.2	69.9	1015	21	4,5,8	5	9	4	21	1	
44	2345	7/26	36°22'	159°01'	72.3	24	13	74.5	71.4	1016	01	4,8	5	9	3	21	1	
45	0350	7/27	36°58'	159°05'	72.4	23	08	74.3	70.9	1015	03	6,8	7	9	3	22	1	34.25
46	0645	7/27	37°24'	159°08'	71.8	21	09	72.5	69.9	1016	01	1,4	3	9	2	21	1	
47	0840	7/27	37°25'	159°09'	71.7	21	09	72.8	70.1	1017	03	4,8	7	9	2	21	1	
48	1230	7/27	37°47'	159°11'	70.4	29	14	70.0	66.4	1018	xx	xx	x	9	3	x	x	34.22
49	1600	7/27	38°16'	159°12'	70.1	29	12	68.9	64.3	1018	03	8	7	9	3	29	2	34.37
50	1850	7/27	38°34'	159°13'	69.8	25	14	69.5	65.9	1019	03	8,4	8	9	2	29	2	
51	2005	7/27	38°35'	159°13'	69.9	25	14	69.5	65.9	1021	50	4	8	9	2	29	2	
52	2345	7/27	38°58'	159°14'	67.7	28	16	67.6	67.3	1021	50	4	8	9	3	29	2	34.12
53	0330	7/28	39°19'	159°14'	67.4	29	11	69.2	65.9	1021	20	6,8	6	9	3	29	2	34.03
54	0645	7/28	39°40'	159°15'	67.1	30	14	67.3	63.5	1022	02	6	7	9	3	29	2	
55	0815	7/28	39°42'	159°15'	66.8	30	14	67.9	64.2	1022	00	x	x	9	x	xx	x	
56	1550	7/28	39°49'	159°18'	65.2	28	15	66.5	65.0	1024	51	6	8	7	3	30	2	
57	1900	7/28	40°10'	159°19'	65.3	25	18	67.0	65.0	1025	03	0	7	9	3	29	3	34.04
58	2200	7/28	40°24'	159°18'	64.9	27	14	66.9	65.0	1026	20	0	7	9	3	29	1	33.98
59	0100	7/29	40°43'	159°18'	63.5	26	08	66.1	63.8	1025	02	00	5	9	2	30	1	33.80
60	0405	7/29	40°49'	159°31'	63.1	24	16	65.0	64.0	1025	51	0	8	9	3	23	1	33.92
61	0600	7/29	40°49'	159°38'	63.7	28	17	66.0	64.3	1025	50	0	9	5	2		1	
62	0830	7/29	40°49'	159°38'	63.5	27	16	65.2	64.5	1027	50	x	x	x	x	xx	x	
63	1700	7/29	40°48'	159°39'	63.3	01	08	61.8	59.9	1027	20	0	8	7	2	28	1	
64	1810	7/29	40°48'	159°39'	63.2	01	08	62.7	60.3	1027	20	0	8	7	2	28	1	
65	2045	7/29	41°03'	159°39'	62.3	36	12	60.2	57.5	1029	02	0	9	5	2	30	1	
66	2345	7/29	41°17'	159°39'	61.8	31	16	59.5	55.0	1029	01	4	3	9	2	30	2	33.73
67	0230	7/30	41°30'	159°39'	60.2	31	14	61.0	54.5	1030	01	4	1	9	2	30	2	33.62
68	0630	7/30	41°20'	159°56'	61.3	35	08	61.0	56.0	1030	03	8	7	9	2	30	2	
69	1645	7/30	41°21'	159°59'	61.5	32	02	60.3	54.8	1031	02	8	7	7	2	30	1	
70	1830	7/30	41°35'	159°58'	60.1	29	09	59.9	54.3	1031	02	8	8	9	1	30	1	33.68
71	2200	7/30	41°52'	159°57'	59.6	32	13	60.8	56.2	1031	02	8	8	9	2	30	1	33.68
72	0100	7/31	42°07'	159°57'	59.7	32	11	58.0	52.2	1030	02	8	8	8	2	33	1	33.71
73	0400	7/31	41°59'	159°41'	59.5	31	06	58.3	52.8	1030	02	8	9	8	2	30	1	33.65
74	0625	7/31	41°46'	159°24'	58.8	31	06	58.0	53.3	1030	02	8	9	8	2	30	1	
75	0740	7/31	41°46'	159°24'	58.7	31	06	57.9	52.9	1030	02	8	9	8	2	30	1	
76	1700	7/31	41°45'	159°22'	58.6	32	06	56.9	52.2	1031	02	8	9	8	2	30	1	33.50
77	2045	7/31	41°25'	158°57'	59.8	35	09	56.7	53.5	1030	53	0	8	7	2	36	2	33.69
78	2205	7/31	41°19'	158°48'	61.0	31	06	57.5	54.0	1031	50	0	8	8	2	31	2	33.69
79	0050	8/1	41°08'	158°36'	61.8	10	07	59.5	55.3	1030	02	0	8	9	0	00	1	33.74
80	0330	8/1	40°59'	158°27'	62.4	10	06	59.3	54.5	1030	02	6	8	9	2	00	1	33.70

Table 14.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46 (cont'd)

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Barometer (mb.)	Weather	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T.)	Force (kt.)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
81	0615	8/1	41°09'	158°24'	61.4	10	07	57.2	53.9	1030	02	6	8	9	2	00	1	
82	0735	8/1	41°09'	158°24'	61.4	10	06	57.3	53.9	1030	02	6	8	9	2	00	1	
83	1715	8/1	41°06'	158°22'	61.5	34	12	58.1	55.2	1031	20	0	8	9	3	34	2	
84	1930	8/1	41°20'	158°22'	60.5	35	10	57.0	52.0	1032	02	0	8	9	3	34	2	33.61
85	2215	8/1	41°34'	158°22'	61.2	03	09	61.2	56.8	1032	02	0	8	9	2	33	2	33.51
86	0010	8/2	41°46'	158°22'	61.9	03	06	59.6	54.0	1032	02	0	8	9	2	33	2	33.62
87	0315	8/2	42°04'	158°22'	61.0	00	05	59.1	53.7	1032	02	0	8	9	1	33	2	33.60
88	0630	8/2	42°19'	158°22'	59.8	35	08	54.9	53.1	1032	02	0	8	9	1	34	2	
89	0740	8/2	42°19'	158°22'	59.8	35	08	54.5	52.2	1032	00	x	x	9	1	xx	x	
90	1735	8/2	42°20'	158°23'	59.2	35	05	54.1	50.1	1032	02	6	8	8	2	32	2	
91	1930	8/2	42°32'	158°26'	58.0	25	12	54.5	51.2	1032	02	6	9	8	2	32	2	33.57
92	2200	8/2	42°47'	158°29'	57.6	30	13	55.0	52.0	1031	02	6	9	8	3	32	1	33.46
93	0030	8/3	43°02'	158°32'	57.2	29	17	55.0	53.0	1030	02	0	8	8	3	30	2	33.35
94	0330	8/3	43°18'	158°36'	57.0	29	17	55.3	52.8	1028	02	0	8	8	4	31	2	33.32
95	0625	8/3	43°10'	158°47'	56.7	28	13	55.3	53.0	1028	02	0	8	8	3	31	1	
96	0745	8/3	43°10'	158°47'	56.5	28	17	54.0	52.0	1028	50	0	8	8	3	31	1	
97	1740	8/3	43°12'	158°44'	56.4	27	22	55.3	53.8	1025	20	0	8	8	4	31	1	
98	1930	8/3	43°24'	158°46'	56.0	26	24	56.0	53.9	1025		0	8	8	4	30	1	33.25
99	2230	8/3	43°43'	158°48'	56.0	26	24	55.5	54.9	1023	20	0	9	6	5	30	4	
100	0030	8/4	43°54'	158°49'	55.7	26	24	55.5	54.7	1022	50	0	9	8	5	30	3	33.22
101	0330	8/4	44°10'	158°52'	55.3	28	22	55.5	54.5	1021	50	0	9	6	5	30	3	33.25
102	0530	8/4	44°16'	158°57'	55.0	25	22	55.6	54.7	1020	63	0	9	6	5	27	4	
103	0630	8/4	44°16'	158°57'	55.0	25	25	55.6	54.7	1020	63	0	9	6	5	27	4	
104	1600	8/4	43°54'	159°38'	54.5	24	23	56.1	55.0	1017	20	0	9	5	5	27	4	33.20
105	1900	8/4	43°49'	159°54'	54.2	25	22	56.0	59.8	1020	02	0	9	6	5	27	4	
106	2020	8/4	43°49'	159°55'	54.2	25	22	56.0	55.0	1020	02	0	9	6	5	27	4	
107	2200	8/4	43°59'	159°46'	54.6	26	22	56.3	55.3	1019	02	0	9	5	5	27	4	33.19
108	0030	8/5	44°15'	159°39'	54.4	27	21	56.3	55.0	1019	02	0	9	5	5	27	4	33.22
109	0330	8/5	44°34'	159°29'	54.4	28	21	53.9	54.1	1018	02	0	9	5	5	28	4	33.26
110	0515	8/5	44°48'	159°23'	54.2	28	21	54.2	51.9	1018	02	0	8	7	5	28	4	33.27
111	0700	8/5	45°00'	159°23'	53.7	29	17	53.3	51.5	1018	51	0	8	x	5	xx	4	
112	0810	8/5	45°02'	159°23'	53.6	29	16	53.5	51.5	1019	20	0	8	x	5	xx	4	
113	1105	8/5	45°14'	159°33'	52.4	30	22	53.7	51.3	1019	00	x	x	x	4	xx	x	33.18
114	1245	8/5	45°30'	159°35'	52.1	30	20	52.0	50.0	1019	02	x	x	x	4	xx	4	33.13
115	1445	8/5	45°46'	159°38'	52.2	31	19	50.7	48.9	1019	02	0	8	6	4	xx	4	33.12
116	1700	8/5	46°06'	159°40'	51.4	28	19	51.9	50.0	1022	02	0	8	6	3	27	4	
117	1810	8/5	46°08'	159°40'	51.4	28	16	51.4	50.0	1022	02	0	8	7	3	27	4	
118	2000	8/5	46°18'	159°42'	51.4	30	16	53.1	52.0	1022	02	0	8	8	3	27	4	33.11
119	2125	8/5	46°30'	159°44'		31	15	52.0	50.5	1023	02	0	8	8	3	27	4	33.03
120	2300	8/5	46°43'	159°45'	50.8	30	15	51.8	50.0	1023	01	0	6	8	3	27	4	33.00

Table 14.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46 (cont'd)

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Barometer (mb.)	Weather	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T.)	Force (kt.)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
121	0100	8/6	47°02'	159°44'	50.8	30	12	52.2	50.0	1023	03	0	8	6	3	29	4	
122	0210	8/6	47°03'	159°44'	51.0	30	12	52.0	50.0	1024	50	0	8	7	3	29	4	
123	0345	8/6	47°18'	159°44'	51.2	29	15	51.4	50.0	1023	16	0	8	7	3	29	1	32.96
124	0530	8/6	47°35'	159°43'	50.8	27	17	51.9	50.0	1024	16	0	8	6	3	29	1	32.98
125	0715	8/6	47°49'	159°42'	50.7	30	13	51.2	50.0	1025	00	x	x	6	3	xx	x	33.01
126	0900	8/6	48°04'	159°42'	49.4	28	13	50.5	49.4	1025	02	0	8	x	3	xx	x	
127	1025	8/6	48°06'	159°42'	49.4	28	13	50.5	49.4	1025	02	0	8	x	2	xx	x	
128	1500	8/6	49°40'	159°47'	49.1	31	12	49.8	49.0	1025	02	0	8	6	2	29	1	32.88
129	1830	8/6	49°12'	159°46'	48.7	28	13	49.9	49.1	1025	43	fog x	9	6	2	28	1	32.84
130	2115	8/6	49°35'	159°45'	48.8	28	05	51.0	49.0	1025	02	0	8	7	2	28	1	
131	2225	8/6	49°36'	159°45'	49.2	28	05	51.0	49.0	1025	02	0	8	7	2	28	1	
132	0100	8/7	49°59'	159°47'	49.9	34	08	52.9	50.1	1025	10	0	8	4	2	29	2	
133	0410	8/7	50°26'	159°47'	49.0	34	18	49.8	46.8	1026	02	0	8	7	2	30	2	32.72
134	0720	8/7	50°53'	159°48'	48.7	32	14	49.9	47.4	1028	02	0	8	8	2	30	2	
135	0825	8/7	50°56'	159°48'	48.6	32	14	48.8	47.1	1028	02	0	8	8	2	30	2	
136	1245	8/7	51°30'	159°51'	48.9	33	19	50.0	48.0	1028	02	0	8	8	2	30	2	
137	1550	8/7	51°59'	159°53'	49.0	30	22	48.5	47.7	1027	02	0	8	9	4	30	2	
138	1945	8/7	52°33'	159°56'	49.3	32	20	50.6	49.7	1028	02	0	8	9	4	31	2	
139	2130	8/7	52°36'	159°56'	49.4	32	19	50.3	48.7	1028	02	0	8	9	4	31	2	
140	0045	8/8	53°06'	159°56'	50.1	29	20	50.7	49.7	1027	01	0	7	9	4	30	2	
141	0345	8/8	53°35'	159°56'	51.0	30	18	51.2	50.0	1026	03	0	8	8	3	30	2	
142	0620	8/8	53°59'	159°55'	52.8	27	18	52.8	50.7	1025	02	0	8	8	3	30	2	
143	0730	8/8	54°00'	159°55'	52.3	--	--	51.5	50.0	1027	02	x	x	x	3	xx	x	
144	1200	8/8	53°41'	160°14'	52.0	21	21	52.5	51.0	1022	02	x	x	8	x	xx	x	
145	1605	8/8	53°11'	160°41'	51.0	24	22	53.7	53.4	1018	45	x	9	2	3	26	1	
146	1930	8/8	52°44'	161°04'	50.7	25	22	54.5	53.3	1018	45	x	9	2	3	26	1	32.75
147	2305	8/8	52°16'	161°28'	50.0	25	20	54.6	53.0	1019	10	x	9	2	3	26	1	
148	0230	8/9	51°49'	161°52'	49.6	25	22	54.0	52.8	1019	45	x	9	2	3	26	4	
149	0600	8/9	51°21'	162°14'	49.7	26	20	53.0	51.9	1019	45	x	9	2	3	26	4	32.69
150	0930	8/9	50°57'	162°35'	49.6	25	20	52.3	51.0	1019	45	x	9	2	3	26	4	
151	1200	8/9	50°38'	162°50'	49.1	26	18	52.5	51.4	1020	45	x	9	0	4	xx	x	
152	1530	8/9	50°16'	163°16'	49.3	27	20	53.1	51.5	1021	43	x	9	3	4	29	3	
153	1940	8/9	50°15'	164°12'	49.0	25	20	53.6	52.5	1025	45	x	9	2	3	27	3	32.76
154	2230	8/9	50°13'	164°53'	49.6	25	19	53.8	52.0	1023	42	x	9	6	3	27	3	
155	0200	8/10	50°10'	165°39'	49.7	28	12	52.7	51.0	1024	47	x	9	2	2	28	1	32.68
156	0530	8/10	50°07'	166°24'	49.8	27	18	52.7	52.0	1025	47	x	9	1	3	26	1	
157	0900	8/10	50°03'	167°08'	49.8	28	15	53.8	51.5	1025	43	x	9	3	3	28	1	32.64
158	1230	8/10	50°00'	167°54'	49.7	24	16	52.1	51.3	1025	45	x	9	1	3	xx	x	
159	1600	8/10	49°56'	168°40'	49.7	22	20	52.9	52.0	1023	01	0	7	7	3	25	3	32.60
160	1930	8/10	49°53'	169°22'	50.0	24	20	53.2	52.8	1021	47	x	9	1	3	xx	x	

Table 14.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46 (cont'd)

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Barometer (mb.)	Weather	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T.)	Force (kt.)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
161	2305	8/10	49°50'	170°11'	50.0	22	27	55.2	53.9	- -	45	x	9	2	4	26	5	32.67
162	0230	8/11	49°46'	170°53'	50.3	22	22	53.1	52.8	1018	45	x	9	2	4	25	5	
163	0600	8/11	49°45'	171°36'	50.1	22	20	54.4	53.2	1016	45	x	9	3	4	26	5	32.65
164	1015	8/11	49°45'	172°24'	50.0	25	22	55.0	52.3	1016	01	x	x	6	4	xx	x	
165	1300	8/11	49°45'	173°00'	50.0	25	22	52.7	50.8	1016	01	x	x	7	4	26	4	32.57
166	1630	8/11	49°48'	173°41'	50.1	24	22	52.7	50.5	1014	01	1,8	4	9	4	25	4	
167	1900	8/11	50°00'	174°00'	50.0	25	24	54.3	51.0	1013	01	1	1	9	4	26	3	
168	2020	8/11	50°00'	174°03'	49.9	25	23	53.0	50.3	1014	02	1	1	9	4	26	4	
169	2220	8/11	49°47'	174°10'	50.4	26	23	52.4	51.6	1015	47	x	9	4	4	24	4	32.49
170	0000	8/12	49°33'	174°18'	50.1	26	21	53.5	52.0	1016	47	x	9	4	4	24	4	
171	0145	8/12	49°18'	174°27'	50.4	28	24	52.8	51.7	1017	45	x	9	5	5	24	4	32.67
172	0330	8/12	49°04'	174°36'	50.3	28	22	52.1	50.6	1019	40	x	9	5	4	24	4	
173	0440	8/12	49°02'	174°36'	50.5	28	22	52.1	50.6	1019	40	x	9	5	4	26	1	
174	0615	8/12	48°48'	174°41'	50.7	29	17	52.7	51.2	1020	40	x	9	6	3	30	3	32.70
175	0745	8/12	48°34'	174°42'	50.9	27	17	52.8	51.5	1022	02	x	9	5	4	xx	x	32.74
176	0930	8/12	48°18'	174°44'	51.2	28	15	53.0	51.8	1022	47	x	9	2	4	29	4	32.83
177	1055	8/12	48°05'	174°45'	51.7	29	18	52.5	51.8	1025	47	x	9	1	3	xx	x	
178	1200	8/12	48°03'	174°45'	51.7	29	18	52.5	51.8	1025	47	x	9	1	3	xx	x	
179	1445	8/12	47°50'	174°52'	52.0	26	12	53.5	51.9	1023	01	x	x	7	3	xx	x	33.00
180	1625	8/12	47°34'	174°53'	52.2	26	10	54.1	52.2	1024	02	1	5	9	2	20	1	33.04
181	1900	8/12	47°14'	174°56'	52.5	28	10	54.8	52.9	1024	02	6	2	9	2	26	1	
182	2000	8/12	47°13'	174°56'	52.7	28	07	56.4	54.0	1024	02	6	2	9	2	26	1	
183	2225	8/12	46°57'	174°59'	53.1	28	11	57.4	54.1	1025	02	6	1	9	2	28	1	33.03
184	0030	8/13	46°44'	174°57'	53.2	30	10	55.5	54.4	1025	02	7	7	8	2	28	1	32.97
185	0305	8/13	46°27'	174°58'	54.3	28	09	58.7	55.5	1025	01	0,2	2	9	2	29	1	32.93
186	0515	8/13	46°12'	174°56'	54.6	28	10	55.5	54.0	1026	47	x	9	2	2	28	1	
187	0620	8/13	46°12'	174°56'	54.7	28	10	55.0	53.9	1026	42	6	4	9	2	28	1	
188	1740	8/13	46°10'	174°56'	54.4	31	08	52.9	51.9	1027	40	0	8	8	2	28	1	
189	1900	8/13	46°02'	174°56'	54.6	33	07	53.5	52.3	1028	40	0	8	8	2	28	1	33.04
190	2120	8/13	45°48'	174°56'	54.7	34	05	54.1	57.0	1028	40	0	8	8	1	34	1	33.05
191	2340	8/13	45°32'	174°56'	55.8	28	02	58.2	54.5	1028	02	8	6	7	2	28	1	33.04
192	0200	8/14	45°18'	174°55'	57.0	--	00	57.8	54.6	1028	02	8	8	7	2	28	1	33.05
193	0415	8/14	45°04'	174°54'	56.8	28	03	57.4	55.2	1027	02	6	8	8	1	28	1	33.07
194	0530	8/14	45°04'	174°54'	56.2	32	06	56.3	55.0	1027	40	0	8	5	2	26	2	
195	0630	8/14	45°12'	174°53'	56.5	32	06	56.5	55.0	1027	40	0	8	5	2	26	2	
196	1740	8/14	45°08'	174°50'	55.9	32	06	57.0	56.1	1026	40	0	8	7	2	26	2	
197	0230	8/15	45°08'	174°47'	56.7	26	08	60.0	54.2	1024	47	x	9	2	1	xx	2	34.41
198	0445	8/15	44°53'	174°47'	57.2	27	12	60.0	57.7	1024	40	0	8	6	2	34	2	33.10
199	0655	8/15	44°39'	174°48'	57.8	27	10	59.8	58.2	1024	47	0	9	4	1	29	1	33.13
200	1745	8/15	44°30'	174°39'	57.2	25	24	58.5	58.0	1016	45	x	9	4	3	24	3	

Table 14.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46 (cont'd)

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Barometer (mb.)	Weather	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T.)	Force (kt.)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
201	1900	8/15	44°24'	174°40'	57.3	01	22	59.0	57.2	1016	45	x	9	5	3	24	3	
202	2115	8/15	44°23'	174°41'	57.1	01	19	59.0	57.2	1016	45	x	9	5	3	24	3	
203	2320	8/15	44°14'	174°43'	57.9	29	22	59.5	58.2	1016	02	6	9	8	4	27	3	33.26
204	0130	8/15	44°00'	174°45'	58.1	29	21	59.0	57.0	1017	02	6	7	8	3	27	3	33.41
205	0350	8/16	43°44'	174°47'	58.7	28	18	59.9	57.6	1018	02	6	8	7	3	28	3	33.37
206	0525	8/16	43°29'	174°48'	59.1	31	19	58.9	57.2	1019	40	6	8	2	3	24	4	
207	0730	8/16	43°29'	174°48'	59.0	32	17	58.9	57.2	1019	40	0	8	5	03	25	4	
208	1810	8/16	43°22'	174°44'	58.9	30	19	61.0	60.0	1016	40	0	8	4	03	29	3	
209	0320	8/17	43°22'	174°43'	59.1	26	09	59.3	58.9	1015	40	x	9	2	3	30	3	
210	0745	8/17	43°22'	174°43'	58.8	26	07	60.8	59.5	1013	53	x	9	3	2	29	1	
211	1745	8/17	43°28'	174°40'	58.8	21	09	60.1	60.0	1006	51	x	9	4	2	21	1	33.27
212	1900	8/17	43°20'	174°45'	59.3	00	00	61.8	61.0	1005	59	x	9	3	1	24	1	33.33
213	2130	8/17	43°06'	174°52'	60.3	32	05	65.1	63.8	1005	43	x	9	3	1	26	1	33.42
214	0000	8/18	42°51'	175°00'	61.4	31	12	63.7	63.0	1005	49	x	9	3	2	30	1	33.49
215	0310	8/18	42°38'	175°03'	61.3	31	14	61.5	59.8	1006	20	x	9	7	3	31	3	33.85
216	0500	8/18	42°47'	175°07'	61.0	29	18	60.1	58.9	1006	40	0	8	7	3	29	3	
217	0710	8/18	42°48'	175°08'	61.0	28	17	60.8	58.9	1007	41	0	6	8	3	29	4	
218	2050	8/18	42°46'	175°08'	61.3	00	00	63.2	58.8	1006	01	0,4	1	9	2	28	1	33.50
219	0530	8/19	42°48'	175°02'	61.4	24	16	62.0	60.8	0999	02	0	8	6	3	23	3	
220	1820	8/19	42°48'	175°11'	60.8	35	24	58.0	56.1	1006	20	0	8	5	4	35	4	33.55
221	2100	8/19	42°25'	175°09'	60.2	36	24	59.3	56.7	1012	01	8	7	7	4	35	4	33.63
222	2340	8/19	42°11'	175°02'	60.6	35	23	59.5	55.3	1011	02	0	9	6	5	36	4	33.71
223	0230	8/20	41°54'	175°04'	61.2	35	19	55.5	51.2	1012	02	0	9	8	3	35	4	33.73
224	0520	8/20	41°35'	175°08'	61.7	36	18	58.8	53.9	1015	01	0	8	8	4	35	4	
225	0630	8/20	41°35'	175°08'	61.5	36	18	58.8	53.9	1015	02	0	8	8	4	35	4	
226	1815	8/20	41°28'	175°06'	63.3	26	02	60.0	59.0	1016	02	0	8	8	2	35	1	
227	2110	8/20	41°28'	175°06'	63.2	18	05	61.0	55.0	1015	02	0	8	8	2	35	1	33.96
228	2120	8/20	41°28'	175°07'	63.0	18	06	61.0	55.0	1015	02	0	8	8	2	35	1	33.96
229	2131	8/20	41°30'	175°07'	62.8	18	06	61.3	54.8	1015	50	0	8	8	2	35	1	33.92
230	2143	8/20	41°30'	175°08'	62.5	18	06	61.3	54.8	1015	50	0	8	8	2	35	1	33.91
231	2157	8/20	41°32'	175°08'	62.0	18	08	61.3	54.8	1015	50	0	8	8	2	35	1	33.81
232	2209	8/20	41°32'	175°08'	61.7	18	08	61.3	54.8	1014	50	0	8	8	2	35	1	33.76
233	0415	8/21	41°28'	175°06'	63.9	20	24	64.0	63.5	1004	61	x	9	4	4	19	3	33.94
234	1945	8/22	41°47'	175°02'	60.2	18	03	59.3	52.1	1021	02	6	9	9	1	04	1	
235	2145	8/22	41°33'	175°02'	64.3	--	00	64.8	57.0	1021	02	6	7	8	1	30	1	
236	2315	8/22	41°33'	175°02'	64.8	00	00	65.6	58.0	1021	02	6	7	8	1	30	1	33.98
237	0030	8/23	41°39'	175°06'	62.1	00	00	64.8	56.6	1020	02	6	7	8	1	30	1	
238	0115	8/23	41°43'	175°09'	60.4	00	00	64.0	55.8	1019	03	6	8	8	1	30	1	33.76
239	0250	8/23	41°50'	175°15'	59.9	03	03	62.5	54.2	1019	02	6	8	7	01	04	2	
240	0415	8/23	41°52'	175°16'	60.0	03	05	62.0	55.8	1019	02	6	8	7	01	04	2	

Table 14.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46 (cont'd)

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Barometer (mb.)	Weather	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T.)	Force (kt.)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
241	0723	8/23	41°35'	175°01'	61.7	03	04	63.7	59.5	1020	00	x	x	8	01	xx	x	33.95
242	1750	8/23	41°35'	175°10'	61.2	09	16	61.2	57.9	1020	02	6	7	7	2	06	2	
243	1900	8/23	41°28'	175°10'	62.9	08	22	62.5	58.0	1020	02	6	7	7	2	06	2	34.07
244	2130	8/23	41°12'	175°10'	64.1	11	17	63.5	60.0	1020	02	6	8	7	2	xx	2	34.15
245	0000	8/24	40°57'	175°10'	63.1	10	18	63.8	60.4	1019	02	6	8	8	3	13	1	34.08
246	0230	8/24	40°39'	175°11'	63.7	11	18	63.7	60.5	1018	02	6	8	8	3	12	1	33.97
247	0355	8/24	40°30'	175°11'	64.1	11	19	62.3	60.5	1018	53	6	9	6	3	13	1	
248	0520	8/24	40°29'	175°11'	64.0	11	20	62.7	61.0	1018	53	6	8	6	3	13	1	
249	0830	8/24	40°12'	175°07'	63.9	14	20	64.0	62.5	1017	40	x	8	6	3	13	1	33.93
250	1040	8/24	39°54'	175°08'	64.6	14	21	65.0	63.6	1016	00	x	x	x	3	xx	x	
251	1250	8/24	39°35'	175°09'	64.0	20	18	65.0	64.5	1014	00	x	x	x	3	xx	x	
252	1510	8/24	39°16'	175°10'	67.8	20	19	70.3	69.3	1013	00	x	x	x	3	xx	x	
253	1645	8/24	39°13'	175°10'	67.9	20	19	71.3	70.2	1013	00	x	x	x	3	xx	x	
254	1900	8/24	38°52'	175°06'	70.7	20	22	72.9	71.8	1014	02	6	8	8	3	20	1	34.47
255	2120	8/24	38°33'	175°03'	69.3	22	23	74.0	72.3	1014	01	4,1	6	9	3	24	1	34.31
256	2320	8/24	38°10'	175°00'	70.3	23	25	73.8	72.5	1015	02	4,1	6	8	3	23	1	
257	0030	8/25	38°00'	174°58'	71.8	21	22	74.6	72.4	1015	02	4,1	6	8	3	21	1	
258	0130	8/25	37°58'	174°58'	71.8	21	22	74.6	72.4	1015	02	4,1	6	8	3	21	1	
259	0445	8/25	38°14'	174°11'	69.9	22	22	73.7	72.1	1014	02	4,1	6	9	3	25	1	34.37
260	0835	8/25	38°32'	173°31'	69.1	28	08	71.3	70.4	1015	02	x	x	x	x	xx	x	34.48
261	1130	8/25	38°48'	172°58'	69.4	23	15	73.5	70.5	1014	02	5,6	6	9	2	xx	x	34.34
262	1445	8/25	39°04'	172°23'	68.0	24	16	72.0	69.1	1014	02	6	7	9	2	24	1	34.36
263	1810	8/25	39°16'	171°44'	67.2	22	13	70.2	68.0	1015	03	6	8	9	2	23	1	
264	2125	8/25	39°25'	171°00'	68.0	22	17	72.0	68.2	1015	02	6	8	9	2	23	1	
265	2225	8/25	39°25'	170°58'	67.7	22	17	70.2	67.4	1015	02	6	8	9	2	23	1	
266	0000	8/26	39°37'	170°55'	67.5	25	18	69.1	67.8	1015	01	5,1	6	9	3	23	1	34.31
267	0230	8/26	39°57'	170°50'	64.5	24	13	68.1	65.0	1015	02	5,1	5	9	2	23	1	34.18
268	0650	8/26	39°50'	170°52'	65.7	23	10	68.2	65.5	1016	00	x	x	8	2	xx	x	34.33
269	1740	8/26	39°53'	170°46'	65.3	24	18	68.9	67.1	1015	47	0	9	4	3	24	1	34.32
270	1925	8/26	40°03'	170°42'	64.4	24	20	68.8	67.0	1015	47	0	9	5	2	24	1	34.12
271	2115	8/26	40°15'	170°38'	64.6	24	18	67.2	66.0	1015	47	0	9	5	2	24	1	34.21
272	2310	8/26	40°28'	170°33'	61.5	20	19	65.0	64.7	1015	47	x	9	1	2	xx	1	
273	0020	8/27	40°28'	170°32'	61.8	20	19	67.0	65.3	1014	47	x	9	1	2	19	2	
274	0150	8/27	40°38'	170°28'	61.9	21	16	67.1	65.0	1013	43	x	9	4	2	18	1	33.86
275	0350	8/27	40°20'	170°16'	63.0	22	18	68.1	66.0	1013	43	x	9	6	2	19	1	33.92
276	0645	8/27	40°15'	170°16'	63.2	22	19	67.5	66.5	1014	65	x	8	x	3	xx	x	33.89
277	1840	8/27	40°16'	170°19'	63.0	18	12	63.6	62.5	1018	01	5	7	7	2	23	1	
278	0110	8/28	40°13'	170°20'	63.1	12	16	63.0	61.2	1018	21	0	9	6	3	20	1	33.93
279	0500	8/28	40°32'	170°18'	63.5	21	18	67.5	66.0	1015	40	x	9	5	3	20	1	33.99
280	0730	8/28	40°58'	170°16'	61.3	19	27	67.0	65.0	1015	00	x	x	6	3	xx	x	33.79

Table 14.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46 (cont'd)

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Baro-meter (mb.)	Wea-ther	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T.)	Force (kt.)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
281	0915	8/28	41°17'	170°15'	61.3	19	26	67.0	64.6	1014	02	x	8	6	3	xx	x	
282	1100	8/28	41°34'	170°14'	61.2	18	28	66.6	65.0	1011	02	x	x	x	4	18	1	33.76
283	1925	8/28	41°26'	170°38'	60.2	xx	12	61.4	58.6	1016	02	0	9	8	4	xx	3	
284	2045	8/28	41°26'	170°39'	60.3	xx	10	61.4	58.6	1010	02	0	9	8	4	xx	3	
285	2315	8/28	41°44'	170°31'	61.4	28	04	60.0	58.4	1018	50	0	8	8	3	26	3	33.99
286	0145	8/29	41°58'	170°23'	61.2	25	09	61.0	58.9	1019	02	0	8	8	3	26	4	34.03
287	0500	8/29	42°21'	170°12'	60.8	27	04	60.0	58.2	1019	01	4,6	6	8	2	28	2	
288	0630	8/29	42°21'	170°12'	61.1	00	00	64.0	59.8	1019	01	4,6	6	8	2	28	2	
289	1750	8/29	42°23'	170°08'	60.4	03	17	57.9	56.1	1019	20	0	8	7	2	03	2	33.89
290	0100	8/30	42°13'	170°11'	61.1	--	14	60.0	57.5	1021	01	4,6	8	8	2		2	34.05
291	0810	8/30	42°50'	169°57'	58.7	30	15	56.0	53.2	1024	02	x	8	8	2	xx	2	33.68
292	1735	8/30	42°46'	170°03'	58.7	32	13	57.5	53.0	1024	02	6,4,8	7	9	2	33	2	33.72
293	1910	8/30	42°56'	169°56'	59.1	07	16	57.5	53.0	1024	01	6,3	5	9	2	08	2	33.78
294	2100	8/30	43°06'	169°48'	59.2	10	18	58.2	53.3	1025	02	8,6,3	4	9	2	07	2	33.74
295	2300	8/30	43°17'	169°40'	57.7	08	18	57.7	54.7	1025	02	6,8	6	8	2	08	2	
296	0005	8/31	43°18'	169°39'	57.5	08	18	58.2	56.9	1025	03	6,8	8	8	2	08	1	
297	0220	8/31	43°35'	169°34'	57.4	11	21	58.9	57.8	1024	02	6,8	8	8	2	08	1	33.46
298	0430	8/31	42°52'	169°31'	57.0	11	19	57.0	55.9	1023	02	6,8	8	8	3	09	1	33.17
299	0700	8/31	44°05'	169°21'	55.3	10	18	56.5	55.1	1023	50	x	9	7	3	xx	1	
300	0835	8/31	44°06'	169°20'	55.0	11	22	55.5	53.9	1022	61	x	9	7	3	11	1	
301	1100	8/31	44°22'	169°14'	54.8	08	20	54.0	54.0	1021	62	x	9	x	3	xx	x	32.87
302	1330	8/31	44°37'	169°08'	54.5	09	34	55.1	54.7	1016	65	x	x	x	3	xx	x	
303	2135	8/31	44°45'	168°40'	54.2	16	10	58.0	57.5	1013	47	x	9	2	3	11	3	32.82
304	0000	9/1	45°05'	168°42'	55.1	18	12	61.0	59.2	1012	53	0	9	3	2	11	1	32.83
305	0200	9/1	45°20'	168°44'	54.9	17	12	60.1	58.3	1011	53	0	9	4	2	11	1	32.90
306	0500	9/1	45°46'	168°46'	55.0	16	13	58.3	58.0	1008	55	0	9	4	2	16	2	
307	0610	9/1	45°46'	168°46'	55.0	16	13	58.3	58.0	1008	55	0	9	4	2	16	2	
308	1900	9/1	45°52'	166°16'	54.6	17	11	57.1	56.3	1009	20	0	9	4	2	16	2	32.85
309	2200	9/1	46°12'	165°41'	54.1	24	15	60.0	56.9	1010	02	0	9	4	2	20	2	32.78
310	0100	9/2	46°23'	165°12'	53.8	19	10	57.6	55.8	1009	45	x	9	3	3	20	3	32.90
311	0345	9/2	46°34'	164°44'	53.3	24	14	55.0	55.0	1009	45	x	9	2	3	20	3	
312	0445	9/2	46°34'	164°44'	53.3	25	14	55.0	55.0	1009	45	x	9	2	3	20	3	
313	1800	9/2	46°34'	164°28'	53.0	33	12	53.0	52.8	1016	40	0	8	6	2	27	2	
314	0030	9/3	46°28'	164°29'	53.3	32	16	55.1	54.5	1016	40	0	9	4	3	27	2	32.84
315	0345	9/3	46°18'	164°30'	53.7	16	08	54.8	53.9	1018	10	0	9	6	2	14	2	32.82
316	0515	9/3	46°05'	164°30'	54.0	11	18	55.0	53.8	1017	45	0	9	4	3	12	2	32.72
317	0645	9/3	45°52'	164°37'	53.8	15	15	55.0	54.0	1016	53	x	9	x	3	xx	x	32.75
318	0815	9/3	45°39'	164°46'	53.9	13	18	54.9	54.8	1013	65	x	x	x	3	xx	x	
319	0920	9/3	45°38'	164°47'	54.0	23	18	55.8	55.0	1012	65	x	9	x	3	16	x	
320	1230	9/3	45°22'	164°55'	54.7	20	24	59.0	58.8	1009	63	x	x	5	03	xx	x	32.51

Table 14.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), Hugh M. Smith cruise 46 (cont'd)

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Barometer (mb.)	Weather	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T.)	Force (kt.)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
321	1530	9/3	45°07'	165°05'	55.3	18	25	59.3	59.0	1008	00	x	9	6	3	xx	x	32.72
322	1915	9/3	44°58'	165°06'	56.1	21	18	59.9	57.6	1009	01	6,4	8	6	3	20	2	32.88
323	2125	9/3	44°44'	165°04'	56.3	21	22	61.5	58.5	1008	01	4,6	6	7	4	21	2	
324	2240	9/3	44°43'	165°04'	56.2	20	26	60.3	57.6	1008	02	4,6	6	7	4	20	2	
325	0215	9/4	44°28'	165°04'	56.4	22	32	58.2	56.3	0808	02	0	8	6	5	20	4	33.09
326	2100	9/4			60.1													33.44
327	0000	9/5			60.9													33.55
3289	0300	9/5			62.7													33.84
3286	0345	9/5			62.3													33.83
329	0600	9/5			64.4													33.86
330	0900	9/5			65.9													33.76
331	1200	9/5			66.5													34.02

Table 15.--Summary of observations at bathythermograph casts (U. S. Navy Hydrographic Office 1956), M/V Paragon

Ser. No.	Time (GCT)	Date, 1958	Latitude N.	Longitude W.	Bkt. temp. (°F.)	Wind		Air temp.		Barometer (mb.)	Weather	Clouds		Visibility	Sea	Swell		Surf. sal. (‰)
						Dir. (°T.)	Force (kt.)	Dry bulb (°F.)	Wet bulb (°F.)			Type	Cover			Dir. (°T.)	Amt.	
1	0720	7/28	41°40'	157°11'	62.7	22	17	-	-	1018	02	4	7	8	3	08	1	
2	2400	7/29	42°20'	156°49'	60.3	27	10	-	-	1027	02	8	5	9	2	27	1	
3	2240	7/30	41°49'	157°09'	61.8	32	05	-	-	1029	02	6	7	9	2	32	1	
4	2150	7/31	41°43'	157°03'	62.0	32	12	-	-	1028	02	6	7	9	2	32	1	
5	2100	8/1	41°38'	157°20'	62.0	32	10	-	-	1030	02	6	7	9	2	32	1	
6	2100	8/2	42°31'	157°08'	57.7	27	10	-	-	1030	02	6	7	9	2	30	1	
7	2005	8/3	42°56'	158°13'	57.4	26	22	-	-	1023	02	6	8	7	4	26	3	
8	2115	8/5	41°16'	161°24'	60.8	27	10	-	-	1026	12	-	9	1	4	28	3	
9	2130	8/6	41°36'	162°40'	60.2	27	05	-	-	1033	02	6	8	6	2	27	1	
10	2215	8/7	41°27'	163°37'	61.4	32	05	-	-	1033	45	-	9	0	2	32	1	
11	2046	8/8	42°12'	163°30'	58.9	33	08	-	-	1033	02	6	8	8	2	33	1	
12	0230	8/9	42°19'	163°10'	58.9	35	12	-	-	1032	02	6	8	8	2	35	1	
13	2245	8/9	42°11'	162°10'	59.2	29	16	-	-	1030	41	2	6	7	3	28	1	
14	2100	8/10	42°15'	160°51'	59.4	31	18	-	-	1027	43	-	9	7	4	31	3	
15	2220	8/11	41°57'	159°12'	58.5	25	25	-	-	1025	43	-	9	7	4	25	3	
16	2140	8/13	42°06'	159°22'	57.7	32	23	-	-	1020	01	6	8	8	4	32	4	
17	2400	8/14	41°50'	159°23'	58.7	32	05	-	-	1021	01	4	5	9	2	32	1	
18	2150	8/15	42°02'	158°57'	59.7	24	05	-	-	1023	02	6	7	9	2	24	1	
19	2230	8/16	42°24'	158°38'	58.7	18	33	-	-	1013	21	6	8	5	4	18	3	
20	2145	8/17	42°24'	158°35'	58.8	05	10	-	-	1013	20	-	9	0	2	27	1	
21	2000	8/18	42°34'	158°27'	58.3	20	25	-	-	1015	28	-	9	0	6	20	7	
22	2300	8/21	42°26'	158°16'	58.7	16	18	-	-	1013	60	6	7	8	4	16	4	
23	2200	8/23	42°30'	157°56'	58.7	27	05	-	-	1023	02	6,8	3	9	2	18	1	
24	2300	8/24	42°02'	159°05'	57.5	14	05	-	-	1023	61	-	9	5	2	14	1	
25	2200	8/25	42°06'	158°45'	59.6	14	07	-	-	1018	47	-	9	0	2	9	1	
26	2120	8/26	41°38'	158°25'	59.9	27	12	-	-	1019	28	-	9	1	2	18	1	
27	2310	8/27	41°43'	157°22'	63.0	19	18	-	-	1024	45	-	9	2	3	19	1	
28	0100	8/29	41°45'	157°09'	64.0	23	15	-	-	1024	02	6	6	9	2	23	1	
29	2133	8/29	41°48'	156°52'	63.5	24	15	-	-	1025	28	-	9	0	3	21	1	
30	2130	8/30	41°46'	157°09'	62.7	23	23	-	-	1021	63	-	9	0	5	23	3	

Table 16.--Log of ship's weather observations, Hugh M. Smith cruise 46
(U. S. W. B. Form 1210F in International Ship Weather Code)[1]

Date, 1958	Latitude N.	Longitude W.	Time (GCT)	Visibility	Wind		Weather		Pressure			Temperature (°F.)			Clouds						Waves		
					Direction	Speed (kt.)	Present	Past	Bar. corr. (mb.)	Characteristic	Amt. change	Dry bulb	Wet bulb	Sea water	Total amount	Amount low	Type low	Height low	Type middle	Type high	Direction	Period	Height
7/22	21.2°	158.3°	0600	99	12	18	02	0	1015.9	2	1.7	77.2	71.0	74.0	2	1	2	5	0	0	09	2	1
7/22	22.0°	158.5°	1200	99	08	12	00	X	1016.6	8	0.9	77.2	70.9	78.6	9	9	X	X	X	X	XX	X	X
7/22	22.0°	158.5°	1800	98	07	15	50	X	1018.0	2	0.9	76.7	71.8	77.9	9	9	X	0	X	X	06	1	3
7/23	23.0°	158.6°	0000	99	07	15	02	X	1018.0	4	0.0	78.8	72.1	78.4	3	3	2	5	0	0	07	2	3
7/23	23.9°	158.6°	0600	99	06	18	02	1	1018.0	2	1.0	76.1	70.6	77.5	5	5	2	4	6	0	05	3	4
7/23	24.7°	158.6°	1200	99	07	15	00	X	1018.6	1	0.7	75.2	70.6	73.3	X	X	X	X	X	X	XX	X	X
7/23	25.6°	158.6°	1800	99	05	10	14	2	1020.3	2	0.7	76.8	71.9	75.6	6	6	7	X	0	0	06	3	3
7/24	26.4°	158.7°	0000	99	07	14	02	2	1020.3	8	1.0	78.3	72.0	76.0	4	4	7	5	6	0	06	3	3
7/24	26.9°	158.6°	0600	99	07	14	02	0	1020.0	0	0.7	75.3	69.8	74.8	3	3	7	2	0	0	07	3	3
7/24	27.8°	158.6°	1200	99	06	12	02	X	1020.0	0	0.0	74.8	69.7	75.5	X	X	X	X	X	X	07	3	3
7/24	28.7°	158.7°	1800	99	10	10	02	0	1020.7	2	1.9	75.9	70.0	74.3	4	4	2	5	0	0	12	2	2
7/25	29.7°	158.9°	0000	99	13	02	01	1	1019.6	7	0.3	75.3	69.6	76.3	4	4	2	4	6	0	12	2	2
7/25	30.6°	159.0°	0600	99	12	10	01	0	1020.0	2	1.0	75.8	67.6	75.5	2	2	4	X	X	X	13	2	2
7/25	31.5°	159.0°	1200	99	16	10	00	X	1018.6	7	0.7	74.3	69.1	74.7	X	X	X	X	X	X	XX	X	X
7/25	32.3°	159.9°	1900	99	19	13	02	1	1018.0	7	0.7	75.0	69.1	74.5	4	4	2	X	6	0	15	2	2
7/26	33.3°	158.9°	0000	99	21	15	02	1	1016.3	7	1.2	76.5	70.1	74.9	2	2	2	5	0	0	16	X	2
7/26	33.9°	158.9°	0600	99	19	14	03	2	1015.9	7	0.5	75.0	71.0	74.8	7	4	8	5	5	X	XX	X	X
7/26	34.8°	159.0°	1300	99	18	18	02	2	1014.9	7	1.0	74.0	70.9	73.3	X	X	X	X	X	X	21	X	2
7/26	35.7°	159.0°	1800	99	25	09	25	6	1014.9	2	0.7	73.2	70.1	73.7	7	7	7	5	X	X	23	4	3
7/27	37.4°	159.2°	0700	99	21	08	03	1	1015.2	2	0.7	72.5	69.9	71.8	3	3	0	X	1	X	21	2	2
7/27	38.2°	159.3°	1200	99	29	14	02	1	1017.6	4	0.0	70.0	66.4	70.4	X	X	X	X	X	X	XX	X	X
7/27	38.4°	159.2°	1900	99	25	14	02	2	1019.6	2	1.0	69.5	65.9	69.8	8	0	0	X	3	X	29	2	2
7/28	39.2°	159.2°	0000	99	28	16	50	5	1021.0	6	0.7	69.6	67.3	67.7	8	8	7	5	6	X	29	2	2
7/28	39.7°	159.3°	0700	99	31	14	02	2	1022.0	2	0.7	67.3	63.5	67.1	8	8	4	X	X	X	29	2	2
7/28	39.7°	159.3°	1300	99	24	16	00	2	1023.4	0	0.3	68.5	66.0	66.3	X	X	X	X	X	X	XX	X	X
7/28	39.9°	159.3°	1800	98	26	11	20	5	1025.1	2	1.7	66.3	64.7	65.2	7	7	6	X	X	X	30	2	2
7/29	40.6°	159.3°	0000	98	25	12	03	2	1025.7	2	0.5	67.0	64.5	63.9	8	8	6	X	X	X	30	2	2
7/29	40.8°	159.7°	0600	96	28	17	50	5	1025.4	1	1.0	66.0	64.3	63.7	9	9	X	0	X	X	30	2	2
7/29	40.9°	159.6°	1300	96	23	16	45	4	1026.1	4	0.0	64.8	63.8	63.3	X	X	X	X	X	X	XX	X	X
7/29	40.8°	159.6°	1800	97	01	08	50	6	1026.8	2	0.3	62.7	60.3	63.2	8	8	7	2	X	X	28	4	2
7/30	41.3°	159.7°	0000	99	31	16	01	2	1029.1	4	0.0	59.5	55.0	61.8	3	3	0	5	X	X	30	4	3
7/30	41.3°	159.9°	0000	99	35	10	03	2	1030.5	2	0.3	61.0	56.0	61.3	7	7	5	5	X	X	XX	X	2
7/30	41.5°	159.9°	1300	99	29	08	02	2	1030.5	7	0.7	60.2	54.8	61.2	8	X	X	X	X	X	XX	X	X
7/30	41.5°	159.9°	1800	99	36	11	02	2	1030.8	1	0.7	59.0	54.0	60.4	8	8	7	4	0	0	34	3	2
7/31	42.0°	160.0°	0000	98	35	10	02	2	1030.8	4	0.0	59.4	53.4	59.8	7	7	4	4	0	0	33	3	2
7/31	41.9°	159.5°	0600	99	32	07	02	2	1030.1	4	0.0	58.0	53.0	58.9	8	8	7	4	0	0	33	3	2
7/31	42.0°	159.6°	1300	99	28	05	02	2	1030.1	7	0.7	58.4	56.2	58.5	X	X	X	X	X	X	XX	X	X
7/31	41.9°	159.5°	1900	99	30	06	02	2	1030.5	2	0.1	59.5	54.0	59.8	8	8	7	X	X	X	28	3	2
8/1	41.2°	158.6°	0000	99	32	06	02	2	1030.1	4	0.0	59.0	56.0	62.5	8	8	7	X	X	X	30	3	2
8/1	41.2°	158.4°	0600	99	10	06	02	2	1029.5	3	0.9	57.3	53.9	61.4	8	8	7	4	X	X	XX	X	X

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[1] All columns in USWB 1210F are not included here. Those deleted are:

Column 2 Day of week
" 3 Octant
" 13 Barometer as read
" 14 Barometer as corrected
" 17 Air temperature, °F.

Column 23 Course of ship
" 24 Speed of ship
" 31 Diff. sea-air, °F.
" 32 Dew point, °F.

Table 16.--Log of ship's weather observations, Hugh M. Smith cruise 46
(U. S. W. B. Form 1210F in International Ship Weather Code) (cont'd)

					Wind		Weather		Pressure			Temperature (°F.)			Clouds						Waves		
Date, 1958	Latitude N.	Longitude W.	Time (GCT)	Visibility	Direction	Speed (kt.)	Present	Past	Bar. corr. (mb.)	Characteristic	Amt. change	Dry bulb	Wet bulb	Sea water	Total amount	Amount low	Type low	Height low	Type middle	Type high	Direction	Period	Height
8/1	41.2°	158.4°	1300	99	34	08	02	2	1029.5	7	0.7	57.4	54.2	61.3	X	X	X	X	X	X	XX	X	X
8/1	41.2°	158.4°	1800	99	04	09	20	5	1030.8	7	0.9	58.4	52.1	60.9	8	8	5	4	X	X	34	4	2
8/2	41.8°	158.4°	0000	99	03	06	02	2	1030.8	4	0.0	59.6	54.0	61.9	8	8	6	4	X	X	33	1	2
8/2	42.3°	158.4°	0600	99	35	06	02	2	1031.8	3	0.3	54.9	53.1	59.9	8	8	6	4	X	X	34	3	2
8/2	42.3°	158.4°	1300	99	01	06	02	2	1032.2	7	0.3	54.7	50.7	59.3	X	X	X	X	X	X	XX	X	X
8/2	43.1°	158.3°	1800	99	35	05	02	2	1031.5	4	0.0	54.1	50.1	59.2	8	8	6	X	X	X	34	2	2
8/3	42.4°	158.4°	0000	99	29	17	02	2	1029.8	7	1.4	55.0	53.0	57.2	8	8	6	X	X	X	34	2	3
8/3	43.1°	158.5°	0600	98	28	13	02	2	1028.1	6	1.7	55.3	53.0	56.7	8	8	6	X	X	X	32	2	3
8/3	43.2°	158.6°	1300	98	30	22	02	2	1026.8	7	1.0	54.2	52.0	56.3	X	X	X	X	X	X	XX	X	X
8/3	43.2°	158.8°	1800	98	27	22	20	5	1025.4	7	0.7	55.2	53.8	56.4	8	8	7	4	X	X	31	3	3
8/4	44.3°	158.9°	0400	97	28	22	20	5	1020.7	7	4.7	55.5	54.5	55.3	9	9	X	0	X	X	31	3	5
8/4	44.3°	159.0°	0600	97	25	22	20	5	1020.3	7	0.9	55.6	54.7	55.0	8	8	7	4	X	X	27	3	6
8/4	44.6°	159.0°	1200	96	24	24	60	6	1019.0	7	0.7	56.9	55.0	54.7	8	8	7	3	X	X	XX	X	X
8/4	43.8°	159.9°	1800	96	36	22	60	6	1018.3	2	0.7	56.2	55.0	54.3	8	8	7	3	X	X	27	2	6
8/5	44.2°	159.8°	0000	97	27	18	02	2	1018.6	4	0.0	56.1	55.0	54.3	8	8	6	3	X	X	27	2	5
8/5	45.0°	159.6°	0700	XX	28	17	60	5	1017.6	2	0.7	53.3	51.5	53.7	8	8	7	3	X	X	XX	X	X
8/5	45.5°	159.4°	1200	XX	30	22	00	X	1019.0	4	0.0	53.7	51.3	52.4	X	X	X	X	X	X	XX	X	X
8/5	46.2°	159.6°	1800	98	28	18	02	2	1022.0	2	2.0	51.9	50.0	51.4	8	8	6	3	X	X	27	4	5
8/6	46.9°	159.7°	0000	98	28	12	02	2	1023.0	1	0.5	51.7	50.3	51.2	8	8	6	3	X	X	30	3	3
8/6	47.6°	159.7°	0600	97	27	17	16	2	1024.7	2	0.5	51.9	50.0	50.8	8	8	6	3	X	X	30	3	3
8/6	48.0°	158.8°	1200	97	28	12	00	X	1025.7	1	0.7	50.8	49.9	49.4	X	X	X	X	X	X	XX	X	X
8/6	49.0°	159.8°	1800	97	28	12	10	4	1025.4	4	0.0	49.9	49.1	48.7	9	9	X	0	X	X	28	3	2
8/7	49.9°	159.7°	0000	95	30	08	10	4	1025.1	7	0.2	53.1	51.2	49.3	9	9	X	0	X	X	30	5	1
8/7	50.8°	159.7°	0600	99	33	18	02	2	1026.8	2	0.7	49.8	47.1	48.8	8	8	6	4	X	X	33	2	2
8/7	51.7°	159.8°	1300	99	33	19	02	2	1028.1	4	0.3	50.0	48.0	48.9	8	8	X	X	X	X	30	2	2
8/7	52.5°	159.8°	1900	99	32	20	02	2	1027.8	4	0.0	50.6	49.7	49.3	8	8	6	4	0	0	31	2	3
8/8	53.0°	160.0°	0100	99	29	20	01	2	1027.1	1	0.3	50.7	49.7	50.1	7	7	6	4	0	0	30	2	4
8/8	53.9°	159.9°	0600	99	27	20	01	2	1025.1	7	2.0	51.2	50.0	52.5	7	7	6	4	0	0	30	2	4
8/8	53.9°	160.1°	1200	99	21	21	01	2	1022.0	7	2.4	52.5	51.0	52.0	X	X	X	X	X	X	XX	X	X
8/8	53.0°	161.9°	1900	92	24	18	45	4	1018.0	0	0.0	53.8	53.4	50.8	X	X	X	X	X	X	31	2	4
8/8	52.4°	161.4°	2300	93	25	20	10	4	1018.6	2	1.4	54.6	53.0	50.0	9	9	X	0	X	X	26	1	3
8/8	51.6°	162.0°	0600	93	26	20	45	4	1018.6	4	0.0	53.0	51.9	49.7	9	9	X	0	X	X	26	3	4
8/9	50.9°	162.6°	1200	90	26	18	45	4	1019.6	1	0.5	52.5	51.4	49.1	9	9	X	0	X	X	XX	X	X
8/9	50.5°	163.8°	1900	93	25	20	45	4	1022.0	2	1.4	53.1	52.5	49.0	9	9	X	0	X	X	27	3	3
8/10	50.3°	165.2°	0000	96	28	20	40	4	1023.7	2	1.7	54.4	51.8	49.4	9	9	X	0	X	X	28	3	3
8/10	50.1°	166.6°	0600	92	27	16	47	4	1025.4	2	0.7	52.7	52.0	49.8	9	9	X	0	X	X	26	3	3
8/10	50.1°	168.1°	1200	92	24	16	45	4	1025.1	6	0.9	52.1	51.3	49.7	9	9	X	0	X	X	XX	X	X
8/10	50.0°	169.8°	1900	92	24	20	45	4	1021.3	7	2.0	53.2	52.8	50.0	9	X	X	X	X	X	23	3	3
8/11	50.0°	170.2°	0000	92	22	27	45	4	1019.3	7	2.0	55.2	53.9	50.0	9	9	X	0	X	X	26	5	5
8/11	49.9°	172.6°	1300	99	25	22	01	1	1015.6	4	0.0	52.7	50.8	50.0	4	4	X	X	X	X	26	4	4

Table 16.--Log of ship's weather observations, Hugh M. Smith cruise 46
(U. S. W. B. Form 1210F in International Ship Weather Code) (cont'd)

					Wind		Weather		Pressure			Temperature (°F.)			Clouds						Waves		
Date, 1958	Latitude N.	Longitude W.	Time (GCT)	Visibility	Direction	Speed (kt.)	Present	Past	Bar. corr. (mb.)	Characteristic	Amt. change	Dry bulb	Wet bulb	Sea water	Total amount	Amount low	Type low	Height low	Type middle	Type high	Direction	Period	Height
8/11	50.0°	174.0°	1900	99	27	24	01	1	1013.2	7	1.4	54.3	51.0	50.0	1	1	4	4	X	X	26	4	4
8/12	49.5°	174.0°	0000	95	26	21	47	4	1015.9	2	1.2	53.5	52.0	50.1	9	9	X	0	X	X	26	4	4
8/12	48.8°	174.7°	0600	97	29	17	40	4	1020.0	2	2.0	52.9	51.2	50.7	9	9	X	0	X	X	30	3	4
8/12	48.0°	175.0°	1200	92	29	18	47	4	1023.4	2	1.7	52.5	51.8	51.7	9	9	X	0	X	X	XX	X	X
8/12	47.3°	174.9°	1800	99	28	10	01	1	1023.7	2	0.5	54.6	52.1	52.7	2	2	5	X	X	X	30	4	2
8/13	46.8°	175.0°	0000	98	30	09	03	1	1025.7	1	1.5	57.0	55.5	53.5	7	7	5	4	0	0	30	4	2
8/13	46.3°	175.0°	0600	99	28	10	28	1	1026.1	2	0.5	55.0	53.9	54.7	4	4	5	3	X	1	28	3	2
8/13	46.2°	175.0°	1200	99	28	10	02	2	1026.1	4	0.0	56.2	55.9	54.7	X	X	X	X	X	X	XX	X	X
8/13	46.2°	174.9°	1800	97	31	08	40	4	1027.8	2	1.2	52.9	51.9	54.4	9	9	X	0	X	X	25	4	1
8/14	45.5°	174.9°	0000	99	28	02	02	2	1028.4	4	0.0	58.2	54.2	55.8	9	9	X	0	X	X	30	3	1
8/14	45.2°	174.9°	0600	96	32	06	40	2	1027.4	7	0.5	57.0	55.5	56.0	8	9	X	0	X	X	26	4	2
8/14	45.2°	175.0°	1300	99	27	10	40	4	1026.8	7	1.0	57.8	56.2	56.0	X	X	X	X	X	X	XX	X	X
8/14	45.2°	174.8°	1800	98	32	06	40	4	1026.4	4	0.0	57.0	56.1	55.9	9	8	6	X	X	X	26	2	2
8/15	45.1°	174.7°	0000	95	30	13	47	4	1025.4	8	0.3	56.5	56.0	56.1	9	9	X	0	X	X	29	3	1
8/15	44.6°	174.8°	0600	95	27	10	47	4	1023.7	6	0.3	59.8	58.2	57.8	9	9	X	0	X	X	28	3	1
8/15	44.6°	174.9°	1300	95	28	18	62	4	1021.0	7	3.1	59.4	58.7	57.4	X	X	X	X	X	X	XX	X	X
8/15	44.5°	174.6°	1800	95	25	24	51	4	1015.6	7	2.7	58.5	58.0	57.1	9	9	X	0	X	X	24	3	3
8/16	44.2°	174.7°	0000	98	29	22	02	2	1016.3	4	0.0	59.5	58.2	58.6	9	9	X	0	X	X	27	3	4
8/16	43.5°	174.8°	0600	96	32	17	40	2	1019.0	2	1.7	58.9	57.2	59.0	8	8	6	X	X	X	25	3	4
8/16	43.5°	174.9°	1300	98	30	20	40	2	1017.6	7	1.4	61.0	60.3	59.2	X	X	X	X	X	X	XX	X	X
8/16	43.5°	174.9°	1800	96	30	19	40	5	1015.9	3	1.0	61.0	60.0	58.9	8	8	X	0	X	X	29	3	3
8/17	43.5°	174.9°	0000	94	27	18	47	4	1015.9	4	0.0	60.0	59.2	58.7	8	8	X	0	X	X	28	2	2
8/17	43.4°	174.7°	0600	95	21	08	47	4	1013.2	7	0.7	62.5	61.0	58.8	9	9	X	0	X	X	21	2	2
8/17	43.1°	174.9°	1300	95	24	15	51	4	1010.2	7	2.0	61.0	60.3	59.0	X	X	X	X	X	X	XX	X	X
8/17	43.3°	174.6°	1800	95	21	09	51	4	1006.1	7	2.0	60.1	60.0	58.8	9	9	X	0	X	X	21	2	2
8/18	42.9°	174.9°	0000	94	31	12	49	4	1005.4	4	0.0	63.7	63.0	61.4	9	9	X	0	X	X	30	2	2
8/18	42.8°	175.1°	0600	97	29	18	40	2	1006.1	4	0.0	60.1	58.9	61.0	8	8	7	X	X	X	29	3	3
8/18	42.5°	175.0°	1300	97	30	20	50	5	1007.5	4	0.0	61.2	58.2	61.0	X	X	X	X	X	X	XX	X	X
8/18	42.5°	175.0°	1900	99	29	08	01	2	1007.1	5	0.0	60.1	56.7	60.8	7	7	6	3	X	X	XX	2	1
8/19	42.5°	175.0°	0000	99	23	14	03	1	1004.1	8	2.4	64.1	60.8	61.7	8	0	0	7	2	X	26	5	2
8/19	42.8°	175.1°	0600	97	24	16	02	6	999.3	7	2.0	62.0	60.8	61.4	8	8	6	X	X	X	23	4	2
8/19	42.8°	175.1°	1300	98	25	16	00	2	1002.4	2	0.7	62.0	59.8	60.7	X	X	X	X	X	X	XX	X	X
8/20	42.2°	175.0°	0000	97	35	23	02	2	1010.8	1	0.9	59.5	55.3	60.6	9	9	X	0	X	X	36	4	5
8/20	41.6°	175.1°	0600	98	36	19	02	2	1014.6	2	2.4	58.8	53.9	61.7	8	8	7	4	X	X	35	3	4
8/20	41.5°	175.1°	1300	98	35	08	02	2	1015.9	2	0.3	58.8	54.0	61.3	X	X	X	X	X	X	XX	X	X
8/20	41.5°	175.1°	1800	98	26	02	02	2	1015.9	6	0.2	60.0	54.0	63.3	8	8	6	4	X	X	35	3	3
8/21	41.2°	175.1°	0600	95	18	28	21	2	1001.0	7	3.9	66.0	65.0	65.3	9	9	X	0	X	X	18	3	5
8/21	41.4°	175.1°	1200	96	25	32	00	2	997.0	7	2.7	66.0	63.6	65.1	X	X	X	X	X	X	XX	X	X
8/21	41.6°	175.0°	1800	98	35	26	02	2	1008.1	2	5.8	59.2	55.0	63.2	7	7	2	4	X	X	34	3	5
8/22	41.3°	175.0°	0100	98	35	19	02	2	1014.9	2	1.2	60.5	55.3	64.3	7	7	2	5	X	X	34	3	4

Table 16.--Log of ship's weather observations, Hugh M. Smith cruise 46
(U. S. W. B. Form 1210F in International Ship Weather Code) (cont'd)

					Wind		Weather		Pressure			Temperature (°F.)			Clouds						Waves		
Date, 1958	Latitude N.	Longitude W.	Time (GCT)	Visibility	Direction	Speed (kt.)	Present	Past	Bar. corr. (mb.)	Characteristic	Amt. change	Dry bulb	Wet bulb	Sea water	Total amount	Amount low	Type low	Height low	Type middle	Type high	Direction	Period	Height
8/22	41.8°	174.9°	0600	98	35	14	02	2	1017.3	2	1.4	57.5	52.0	60.0	7	7	2	5	0	0	35	3	4
8/22	42.2°	175.0°	1200	98	34	08	00	2	1020.0	2	0.7	59.3	52.0	59.2	X	X	X	X	X	X	XX	X	X
8/22	41.6°	175.0°	1900	99	18	03	02	2	1021.0	2	0.5	59.3	52.1	60.2	9	9	X	0	X	X	05	4	2
8/23	41.5°	175.1°	0000	99	00	00	02	2	1023.0	4	0.0	65.6	58.0	64.8	8	8	5	5	X	X	33	2	4
8/23	41.7°	175.1°	0600	98	07	09	01	2	1014.3	4	0.0	61.0	57.7	60.4	7	7	5	6	X	X	07	4	2
8/23	41.6°	175.0°	1200	99	06	12	00	2	1019.6	7	0.3	63.8	58.4	61.4	X	X	X	X	X	X	XX	X	X
8/23	41.6°	175.0°	1800	98	09	16	02	2	1020.0	4	0.5	61.2	57.9	61.2	7	7	5	5	X	X	06	2	2
8/24	40.9°	175.1°	0000	99	10	18	02	2	1018.6	4	0.4	63.8	60.4	63.1	8	8	5	4	X	X	13	2	2
8/24	40.6°	175.0°	0600	97	11	20	53	5	1017.3	4	0.0	62.7	61.0	64.0	8	8	7	4	X	X	13	3	2
8/24	39.7°	175.0°	1300	XX	20	18	00	X	1013.9	7	1.7	65.0	64.5	64.0	X	X	X	X	X	X	XX	X	X
8/24	38.9°	175.1°	1900	99	20	22	02	2	1013.9	2	0.0	72.9	71.8	70.7	8	8	5	4	X	X	20	2	3
8/25	38.4°	175.0°	0000	99	23	25	01	2	1014.9	2	1.0	73.8	72.5	70.3	7	7	4	6	3	0	23	1	3
8/25	38.3°	173.9°	0600	99	22	18	02	2	1013.9	4	0.0	74.8	71.3	69.5	9	9	X	0	0	0	24	1	2
8/25	38.7°	172.9°	1200	99	23	15	02	2	1014.2	0	0.0	73.5	70.5	69.4	6	6	X	X	X	X	XX	X	X
8/25	39.3°	171.7°	1800	99	22	13	03	2	1014.9	1	0.9	70.2	68.0	67.2	8	8	6	6	X	X	22	3	2
8/26	39.6°	170.9°	0000	99	25	18	01	2	1014.9	4	0.0	69.1	67.8	67.5	6	6	0	X	9	2	27	2	2
8/26	39.8°	170.9°	0600	99	28	12	01	2	1014.9	2	0.7	68.0	65.5	65.7	6	6	0	X	9	3	27	2	2
8/26	39.9°	173.9°	1300	99	28	10	15	2	1015.9	7	0.7	68.3	61.3	65.1	X	X	X	X	X	X	XX	X	X
8/26	40.0°	170.6°	1800	95	24	18	47	2	1014.2	2	0.3	68.9	67.1	65.3	9	9	X	0	X	X	24	2	2
8/27	40.4°	170.5°	0000	93	20	19	47	4	1013.2	7	1.4	67.0	65.3	61.9	9	9	X	0	X	X	19	3	2
8/27	40.3°	170.3°	0600	XX	22	19	65	2	1013.5	2	0.5	67.5	66.5	63.2	8	8	X	X	X	X	XX	X	X
8/27	40.3°	170.3°	1300	98	27	08	00	2	1016.6	2	2.0	65.0	62.3	62.8	X	X	X	X	X	X	XX	X	X
8/27	40.4°	170.3°	1800	98	18	12	01	4	1018.3	8	0.3	63.6	62.5	63.0	7	7	0	5	2	0	23	3	2
8/28	40.4°	170.3°	0000	98	16	14	21	2	1018.3	4	0.0	64.1	62.5	62.9	8	8	6	4	X	X	18	2	2
8/28	40.7°	170.3°	0600	97	23	15	02	2	1014.6	7	1.4	66.0	65.0	62.5	7	7	6	4	X	X	19	2	2
8/28	41.2°	170.3°	1200	XX	18	32	02	2	1010.2	7	1.9	66.6	65.0	61.2	X	X	X	X	X	X	18	2	4
8/28	41.5°	170.6°	1800	98	33	24	02	2	1014.9	2	3.4	63.2	59.5	60.5	8	8	6	4	X	X	23	3	6
8/29	41.8°	170.5°	0000	99	28	04	50	2	1018.3	2	1.0	60.0	58.4	61.4	8	8	6	4	X	X	26	3	4
8/29	42.4°	170.2°	0700	99	00	00	01	2	1019.6	4	0.4	64.0	59.8	61.1	6	6	4	4	X	X	28	3	2
8/29	42.4°	170.1°	1200	99	10	06	00	2	1019.6	4	0.0	61.9	59.6	61.0	X	X	X	X	X	X	XX	X	X
8/29	42.3°	170.2°	1800	98	03	17	20	2	1019.3	2	0.7	57.9	56.1	60.4	8	8	6	5	0	0	03	2	2
8/30	42.7°	170.0°	0600	99	02	18	02	2	1022.4	2	0.7	56.1	53.5	59.6	8	8	1	5	0	0	03	2	2
8/30	42.8°	170.0°	1200	99	10	12	00	2	1023.7	2	0.3	59.7	54.1	58.8	X	X	X	X	X	X	XX	X	X
8/30	42.8°	170.0°	1800	99	32	13	01	2	1023.7	4	0.0	57.5	53.0	58.7	7	7	4	4	6	1	33	2	2
8/31	43.3°	169.6°	0000	98	11	17	03	2	1024.7	2	0.9	58.2	56.9	57.5	8	8	4	5	X	X	08	2	1
8/31	44.1°	169.4°	0700	98	10	18	50	2	1023.0	5	0.5	56.5	55.1	55.3	9	9	X	0	X	X	XX	2	2
8/31	44.5°	169.1°	1100	98	08	20	62	2	1021.0	5	3.1	55.0	54.0	54.8	X	9	X	0	X	X	XX	2	2
8/31	44.4°	168.5°	1800	96	09	18	45	6	1013.9	5	0.7	57.7	57.7	53.9	9	9	X	0	X	X	10	3	4
9/1	45.1°	168.7°	0000	94	18	12	45	4	1011.5	7	0.9	61.0	59.2	55.1	9	9	X	0	X	X	11	2	2
9/1	45.7°	168.8°	0600	96	16	13	55	6	1008.5	7	2.4	58.3	58.0	55.0	9	9	X	0	X	X	16	2	3

Table 16.--Log of ship's weather observations, Hugh M. Smith cruise 46 (U. S. W. B. Form 1210F in International Ship Weather Code) (cont'd)

					Wind		Wea-ther		Pressure			Temperature (°F.)			Clouds						Waves		
Date, 1958	Latitude N.	Longitude W.	Time (GCT)	Visibility	Direction	Speed (kt.)	Present	Past	Bar. corr. (mb.)	Characteristic	Amt. change	Dry bulb	Wet bulb	Sea water	Total amount	Amount low	Type low	Height low	Type middle	Type high	Direction	Period	Height
9/1	45.9°	167.5°	1200	96	20	13	51	6	1007.8	7	1.0	59.0	57.4	55.2	X	X	X	X	X	X	XX	X	X
9/1	46.0°	166.3°	1800	95	17	11	20	4	1008.8	4	0.0	57.1	56.3	54.6	9	9	X	0	X	X	16	3	5
9/2	46.4°	165.2°	0000	93	19	10	45	4	1009.1	1	0.3	57.0	55.2	53.9	9	9	X	0	X	X	21	3	4
9/2	46.6°	164.7°	0700	93	18	13	45	4	1009.8	2	0.7	56.4	54.8	53.4	9	9	X	0	X	X	XX	X	X
9/2	46.6°	164.6°	1200	93	26	12	00	4	1010.8	2	1.0	55.8	54.0	53.0	X	X	X	X	X	X	XX	X	X
9/2	46.6°	164.5°	1800	97	33	12	40	4	1015.6	2	2.5	53.0	52.8	53.0	8	8	6	4	0	0	27	3	3
9/3	46.5°	164.5°	0000	95	32	16	43	4	1018.3	7	0.2	55.1	54.5	53.3	9	9	X	0	X	X	27	3	3
9/3	46.0°	164.6°	0600	96	11	18	45	4	1016.6	7	1.7	55.0	53.8	54.0	9	9	X	0	X	X	12	2	2
9/3	45.4°	164.9°	1200	96	20	24	63	6	1009.1	7	2.4	59.0	58.9	54.7	X	X	X	X	X	X	XX	X	X
9/3	45.0°	165.1°	1800	96	22	24	43	4	1008.5	5	0.2	59.8	58.2	55.9	9	9	X	0	X	X	20	3	5
9/3	45.0°	165.1°	1900	97	21	18	01	5	1009.1	2	0.3	59.9	57.6	56.1	8	8	4	4	X	X	20	3	4
9/4	44.6°	165.1°	0000	97	21	30	02	2	1008.1	6	0.7	60.0	57.2	56.1	8	8	6	4	0	0	20	2	3
9/4	44.0°	164.7°	0600	97	21	28	02	2	1008.5	1	0.4	59.0	55.9	56.1	8	8	6	4	0	0	20	3	6
9/4	43.3°	164.4°	1200	97	25	22	00	2	1013.9	2	2.4	57.2	55.7	58.3	X	X	X	X	X	X	XX	X	X
9/4	42.9°	163.9°	1800	98	28	21	01	1	1021.0	2	4.1	58.2	56.5	58.8	4	4	2	4	0	0	28	3	4
9/5	41.9°	163.6°	0000	98	29	10	02	2	1023.4	1	0.7	61.4	57.9	60.9	9	9	X	0	X	X	24	3	3
9/5	40.6°	163.4°	0600	98	35	10	02	2	1025.1	2	1.4	61.0	58.8	64.4	8	8	X	X	X	X	XX	2	3
9/5	39.7°	163.4°	1200	99	35	14	02	2	1025.4	4	0.0	61.7	58.5	66.4	8	8	6	4	X	X	34	2	3
9/5	38.6°	163.4°	1800	99	02	17	60	2	1025.4	2	0.7	60.7	60.2	69.0	9	9	X	0	0	0	30	2	3
9/6	37.5°	163.1°	0000	96	02	21	63	5	1025.4	7	0.7	64.7	64.0	69.5	9	9	X	0	X	X	04	2	3
9/6	36.3°	162.8°	0700	96	05	24	63	5	1025.1	2	0.5	70.9	68.5	72.9	9	9	X	0	X	X	XX	X	X
9/6	35.7°	162.6°	1300	97	03	20	00	2	1024.0	4	0.3	72.0	68.5	77.5	X	X	X	X	X	X	XX	X	X
9/6	34.8°	162.2°	1800	99	05	21	01	2	1023.7	2	0.3	74.2	70.1	77.5	6	6	2	4	6	X	04	3	3
9/7	33.9°	161.9°	0000	99	06	13	02	1	1022.0	7	1.7	77.0	71.7	77.8	3	3	2	4	6	0	02	3	3
9/7	33.0°	161.6°	0600	99	05	11	00	1	1021.7	3	0.7	76.9	72.0	77.4	X	X	X	X	X	X	XX	X	X
9/7	32.1°	161.2°	1200	99	06	11	01	1	1020.7	7	0.7	75.3	71.5	77.0	3	3	2	X	X	X	XX	X	X
9/7	31.1°	160.8°	1800	99	06	11	01	0	1020.7	4	0.0	77.0	72.0	77.4	2	2	1	5	0	1	09	2	1
9/8	30.0°	160.6°	0000	99	06	10	02	0	1019.3	7	1.5	77.5	70.9	78.1	2	2	2	5	0	1	08	2	1
9/8	29.1°	160.3°	0600	99	06	14	00	0	1019.0	2	0.7	76.4	72.2	77.2	X	X	X	X	X	X	XX	X	X
9/8	28.3°	160.2°	1200	99	09	08	63	X	1019.0	7	0.7	76.3	72.2	77.3	X	X	X	X	X	X	XX	X	X
9/8	27.0°	159.8°	1800	99	08	14	02	0	1019.0	2	0.3	78.0	73.0	78.0	3	3	2	6	0	1	09	2	2
9/9	26.2°	159.4°	0000	99	08	13	03	0	1018.3	5	0.7	77.4	72.6	78.1	4	4	2	6	0	1	08	2	2
9/9	25.2°	159.1°	0600	99	08	19	03	1	1019.3	2	0.8	77.2	72.7	77.8	5	6	2	4	1	X	08	2	2
9/9	24.2°	158.7°	1200	99	08	13	00	1	1018.6	7	1.7	77.8	73.1	78.3	X	X	X	X	X	X	XX	X	X
9/9	23.0°	158.5°	1800	99	08	19	02	0	1019.0	2	0.3	78.4	73.2	78.6	2	2	2	5	0	0	06	2	1
9/10	22.3°	158.5°	0000	99	05	21	02	0	1017.6	7	1.0	78.8	73.2	79.0	4	4	2	5	X	X	09	2	2

Table 17.--Summary of observations made at submarine photometer stations, Hugh M. Smith cruise 46

Date, 1958	Zone[1] time	Lat. N.	Long. W.	Sea[2]	Cloud cover	Secchi disc (m.)	Photometer depth (m.) at 50, 10, 5, and 1 percent of surface light			
							50%	10%	5%	1%
7/23	1250	26°07'	158°38'	2	3	25	14	35	82	125
7/24	1245	29°29'	158°51'	1	5	35	18	47	72	118
7/25	1255	33°05'	158°50'	1	2	31	17	47	69	105
7/26	1300	36°22'	159°01'	3	1	18	17	32	42	60
7/28	1230	39°00'	159°14'	3	8	13	7	21	33	56
7/28	1000	40°11'	159°18'	3	1	15	4	15	53.5	--
7/28	1230	40°31'	159°18'	2	8	17	5	19	28	52
7/29	2100	41°05'	159°39'	2	8	17	4	13	23.5	46
7/29	1245	41°18'	159°39'	2	2	18	5	27	39	57
7/29	1600	41°30'	159°39'	2	1	18	8	20	29	62
7/30	0830	41°37'	159°58'	2	6	13	1	15	31	51
7/30	1230	42°03'	159°57'	2	6	16	--	13	20	46

[1] Time lowering began; Secchi disc and photometer lowered at same time.

[2] For coded values see U. S. Navy Hydrographic Office (1956).

APPENDIX A

CARBON FIXATION (C_{14}) AND PHYTOPLANKTON DATA FROM HUGH M. SMITH CRUISE 46

By

Mikihiko Oguri
Junior Botanist
University of Hawaii[1/]

Primary productivity measurements were made during the cruise using the radiocarbon tracer technique as modified by Doty and Oguri (1958) from that first described by Steemann Nielsen (1952). This technique consists of introducing a known quantity of radiocarbon to a sample of water containing the natural phytoplankton population. Following a period of incubation at a uniform light intensity, the water is filtered off leaving the phytoplankton on the filter. These filters are stored in a dessicator for later determination of the amount of radiocarbon biologically fixed. From this the total carbon uptake may be calculated.

Pigment concentrations were determined by the method described by Richards and Thompson (1952). Phytoplankton from a measured volume of sea water was collected on a Millipore filter. These filters were stored in a darkened, refrigerated dessicator. Upon return to the laboratory the pigments were extracted with 90-percent acetone and the extinctions of the extract for the wave lengths of peak absorbance for the pigments were spectrophotometrically determined. Conversion of the extinction values obtained to units of pigment was accomplished by use of the formulae listed by Richards and Thompson (1952).

LITERATURE CITED

DOTY, MAXWELL S. and M. OGURI
1958. Selected features of the isotopic carbon primary productivity technique. Rapports et Proces-Verbaux des reunions, Conseil Permanent International pour l'Exploration de la Mer 144: 47-55.

RICHARDS, FRANCIS A. and T. G. THOMPSON
1952. The estimation and characterization of plankton populations by pigment analyses. II. A spectrophotometric method for the estimation of plankton pigments. Journal of Marine Research 11(2): 156-172.

The tabulated data on carbon fixation and photosynthetic pigments are arranged in the chronological order of sampling. Unless otherwise specified, the samples were from the surface. Where the position of sampling is not specified, it is understood to be the same as that of the preceding sample.

The word "Carboy" appearing in the "Station" column of the table as a source of samples refers to three occasions during the cruise when a 5-gallon container was filled with surface water, from which samples were subsequently drawn at intervals to study the diurnal periodicity of production. The carboys were in each case filled at the position specified immediately before their first mention, and the subsamples were drawn from them and processed when regular surface samples were taken.

[1/] Work done under contract at-(04-3)-15 with the U. S. Atomic Energy Commission.

The values in the table are to be regarded as preliminary and subject to correction when more refined methods of calculation have been applied to the data. The original data are in Notebook 36: 1-104, on file at the Botany Department, University of Hawaii.

Station	Time of sampling	Mg C/ hr./m.^{3}	Photosynthetic pigments					Astacine carotinoids
			Chlorophyll			Carotinoids	Total	
			-a	-b	-c			
27°08'N 158°38'W	2005	*.006 .036	.5687	.4632	5.1590	-.3992	5.7917	.6141
30°00'N 158°50'W	1610	-.007	.7112	.5270	4.5598	-.3595	5.4385	.5953
Carboy 1	1605	.072	.2940	.5446	4.3476	-.3343	4.8519	.5555
30°58'N 158°52'W	2325	.019	.7239	.8382	3.0002	.1003	4.6626	.3965
Carboy 1	2320	.010	.8747	.6505	6.7292	-.3710	7.8834	.7120
32°25'N 158°50'W	0815	.061	2.0818	1.9135	12.8176	-1.1427	15.6702	1.7906
Carboy 1	0810	.070	1.4443	1.3056	6.4954	-.4827	8.7626	1.0088
34°01'N 158°54'W	2011		.8148	.4242	5.2352	-.1803	6.2939	.5001
20M	2014	.037				-.3346	-.3346	.4656
35°39'N 158°58'W	0823	.208				.0184	.0184	.1262
20M	0823	.317	.7995	.5018	4.3461	-.2667	5.3807	.5859
37°24'N 159°08'W	2010	.092				.0938	.0938	.0620
38°34'N 159°13'W	0805	.264	.4896	.4093	2.5934	-.4131	3.0792	.7174
20M	0805	.498	.5191	.0861	2.9825	-.1221	3.4656	.3290
40°10'N 159°19'W	0815	.863	1.0630	.9878	4.4640	-.3813	6.1335	.6909

* Average of two unusually widely different replicate values.

Station	Time of sampling	Mg C/ hr./m.^{3}	Photosynthetic pigments					Astacine carotinoids
			Chlorophyll			Carotinoids	Total	
			-a	-b	-c			
20M	0815	1.934	.6490	.0280	.6313	-.1959	1.1124	.4272
40°49'N 159°38'W	1935	.193	.2842	.4036	.9108	-.0139	1.5847	.2205
	0630	2.341	.3082	.3795	1.9179	-.0916	2.5140	.3268
41°20'N 159°56'W	1945	.276	.1018	.0851	.5390	-.5069	.2190	.3819
41°39'N 159°58'W	0832	1.202	1.6733	.6279	6.2003	-.4557	8.0458	.7366
20M	0832	1.292	.3209	.0712	.6249	-.0911	.9259	.3437
41°52'N 159°32'W	1932	.236	.5478	.3149	2.1213	-.0594	2.9246	.2409
41°25'N 158°57'W	0833	1.391	.2453	.1394	.4511	.0528	.8886	.1591
20M	0833	1.194	3.7189	2.1810	11.4684	-1.1189	16.2494	1.9668
41°09'N 158°24'W	1935	.305	1.1525	.9249	5.0781	-.3225	6.8330	.6962
41°20'N 158°22'W	0840	1.454	1.9707	1.6386	8.6419	-1.5397	10.7115	1.4325
20M	0840	1.357	.7322	.6120	3.8782	-.0089	5.2135	.3970
42°19'N 158°22'W	1945	.309	.3284	.0953	1.4297	.0832	1.9366	.1201
42°32'N 158°26'W	0833	1.333	1.0210	.7700	2.1332	.0365	3.9607	.3797
20M	0833	1.894	1.1660	.7110	5.7198	-.1240	7.4728	.5588
43°10'N 158°47'W	1950	.565	.4985	.2096	2.2822	-.0048	2.9855	.2358
43°24'N 158°46'W	0841	1.246	.6205	.2066	.8136	.0919	1.7326	.2271
20M	0841	1.409	.6052	1.2857	1.8394	-.2079	3.5224	.5978

Station	Time of sampling	Mg C/ hr./m.^{3}	Photosynthetic pigments					Astacine carotinoids
			Chlorophyll			Carotinoids	Total	
			-a	-b	-c			
44°16'N 158°57'W	1847	.543	.2256	.0626	.0782	.0986	.4650	.1227
43°49'N 159°54'W	0815	1.227 .668	.5315	.2629	.9406	.0431	1.7781	.2795
20M	0815	1.070	1.1238	.9996	6.2806	-.3061	8.0979	.8117
45°00'N 159°23'W	2010	.415	.5488	.1978	1.4835	-.1107	2.1194	.4668
46°10'N 159°41'W	0807	.931 .675	.4386	.4075	1.8420	-.0002	2.6879	.2385
20M	0807	.628	1.0997	.7695	4.0266	-.2799	5.6159	.5870
47°49'N 159°42'W	2025	.231	.3548	.3837	.8543	.0880	1.6808	.1408
49°12'N 159°46'W	0745	.539	.5771	.3521	1.9013	-.1446	2.6859	.3698
20M	0745	.524	.6454	.1430	1.2565	-.1291	1.9158	.5436
50°53'N 159°48'W	2033	.212 .439	.3428	.1688	1.8943	-.0590	2.3469	.2669
52°33'N 159°56'W	0854	.639	.6436	.4352	1.3400	-.0586	2.3602	.3569
20M	0854	.688	.5068	.2091	1.5141	-.0512	2.1788	.3835
52°44'N 161°04.5'W	0845	.466	.6885	.3532	2.4340	-.0740	3.4017	.3863
20M	0840	.584	.4972	.0215	.4836	.0884	1.0907	.2296
51°42'N 161°57'W	1620	.314	3.0233	2.5357	16.2381	-1.2595	20.5376	2.1560
Carboy 2	1615	.282	.4857	.1326	3.5513	.0125	4.1821	.3653
51°13.2'N 162°21.2'W	2000	.140	.5783	.4429	4.1155	-.2162	4.9205	.4422
Carboy 2	2005	.135	.6297	.1902	1.5014	-.0995	2.2218	.3367

Station	Time of sampling	Mg.C/ hr./m.^{3}	Photosynthetic pigments					Astacine carotin-oids
			Chlorophyll			Carotin-oids	Total	
			-a	-b	-c			
20M	2000	.202 .295	.5476	.8817	3.8608	-.3274	4.9627	.7151
50°41'N 162°48'W	2438	.308	.2891	.2005	-.4319	-.0124	.9091	.2391
Carboy 2	2430	.124	.3301	.2127	2.4903	.0789	3.1120	.2879
50°15.2'N 164°12'W	0815	.414	.2854	.2386	1.5119	-.1010	1.9349	.3949
Carboy 2	0913	.123	.3558	.6323	3.7112	-.1224	4.5769	.4367
20M	0822	.435	.7613	.5292	2.8759	-.2047	3.9617	.5398
50°05'N 166°43.5'W	2005	.742	.5027	.1467	1.1708	.1001	1.9203	.1606
49°53.5'N 169°19.5'W	0815	.457 .712	.5094	.0187	5.0960	-.1584	5.4657	.4531
49°45'N 171°46'W	2005	.562 .294	.8556	.6034	3.6136	-.2801	4.7925	.4987
50°00'N 174°03'W	0815	1.139	1.9260	1.4818	8.2159	-.6615	10.9622	1.1273
48°41.5'N 174°41.5'W	2005	.365	.5103	.3674	1.8755	-.0453	2.7079	.3339
47°14'N 174°56'W	0809	.709	.6606	.4720	3.0612	-.1590	4.0348	.3927
20M	0809	.827	.4454	.3724	2.3594	-.0791	3.0981	.4575
46°12'N 174°56'W	2000	.384	2.0628	2.1291	6.1682	-.8975	9.4626	1.4518
46°02.3'N 174°56.5'W	0810	.489	.4909	.3525	4.7959	-.3662	5.2731	.6319
20M	0810	.398	3.9040	3.6363	20.6902	-1.8119	26.4186	2.7997
45°12'N 174°53'W	1925	.402	.3441	.4639	1.7047	-.2256	2.2871	.4088
45°08'N 174°44'W	0835	.469	.2995	.3817	3.1645	-.1493	3.6964	.3569

Station	Time of sampling	Mg C/hr./m.^{3}	Photosynthetic pigments					Astacine carotinoids
			Chlorophyll			Carotinoids	Total	
			-a	-b	-c			
24M	0845	.245	.1803	.0744	.5385	-.3533	.4399	.8027
31M	0845	.186	.4465	.4380	.9695	-.3363	1.5177	.8704
44°39'N 174°48'W	1940	.422	.4678	.4409	1.8918	-.0108	2.7897	.2699
44°24'N 174°40'W	0815	.597 .924	1.9040	1.5547	9.1005	-.8063	11.7529	1.3914
20M	0815	1.079	.3913	.2111	-.1378	.0885	.5531	.2501
43°29'N 174°48'W	1920	.560	.4040	.1344	1.3791	-.0431	1.8744	.2650
43°22'N 174°43.5'W	0835	.958	.3979	.1959	2.1992	-.0380	2.7550	.2899
20M	0835	1.060	.6082	.4202	4.2589	-.4820	4.8053	.8155
43°22'N 174°43'W.	1935	.615	.6312	.3369	2.6294	-.0191	3.5784	.3351
43°20'N 174°45'W	0805	.968	.3341	.2347	3.2088	-.0238	3.7538	.2574
20M	0805	.608	.5615	.0524	2.6310	.0517	3.2966	.2195
42°48'N 175°08'W	1950	.412	1.2090	.9920	6.6222	-.4018	8.4214	.8473
20M	1950	.334	.5888	.4922	3.1188	-.0642	4.1356	.4023
42°46'N 175°08'W	0900 1015	.512	2.0548	1.8246	9.6273	-.8236	12.6831	1.4468
2M		.474	.4320	.2216	1.5272	-.0659	2.1149	.3754
6M		.651	.2650	.2982	1.1292	-.0815	1.6109	.3505
12M		.696	.2242	.2687	.8193	.0647	1.3769	.1954
20M		.641	.5236	.4037	3.1723	-.1593	3.9403	.5081
25M		.312	.4870	.3662	1.4906	-.0598	2.2840	.4151

Station	Time of sampling	Mg C/ hr./m.^{3}	Photosynthetic pigments					Astacine carotinoids
			Chlorophyll			Carotinoids	Total	
			-a	-b	-c			
39M		.371	.3152	.0699	.6138	.0162	1.0151	.3428
42°48'N 175°02'W	1940	.119 .417	.3835	.1113	1.6694	.0303	2.1945	.2303
42°42'N 175°11'W	0738	.872	1.1993	.8451	5.1572	-.5331	6.6685	1.0280
20M	0738	.973	.4036	-.0707	1.8017	-.0796	2.0550	.2964
41°35'N 175°08'W	1925	.401	.3938	.4432	.7464	.0399	1.6233	.1791
41°28'N 175°06'W	0815	.805	.9628	.9074	3.8936	-.5257	5.2381	.9327
20M	0815	1.281	.7638	.6420	1.6083	.1320	3.1461	.2567
41°28'N 175°06'W	1350 63.0°F	.765	.5127	.2444	3.0926	-.0550	3.7947	.3146
20M	1350 63.0°F	.768	.8155	.2485	3.9632	-.2965	4.7307	.6195
OM	1415 61.7°F	.985	.1472	.1231	.7797	-.3947	.6553	.9536
20M	1415 61.7°F	.980	.3513	-.0765	.8322	-.1804	.9266	.4577
OM	1437 61.8°F	1.031	.7059	.6321	1.5866	-.2029	2.7217	.5335
OM	1449 62.1°F	1.023	.4150	.7573	3.3812	-.1920	4.3615	.5624
OM	1505 62.2°F	.944	.1170	.0039	1.7238	.0784	1.9231	.2562
OM	1515 62.7°F	1.039	1.0000	.9124	4.3943	-.2778	6.0289	.6446
41°33'N 175°02'W	1100	.605	2.1328	1.8835	12.3831	-1.0122	15.3872	1.6641
20M	1100	.933	1.2318	1.1025	5.6885	-.3019	7.7009	.8031

Station	Time of sampling	Mg C/ hr./m.^{3}	Photosynthetic pigments					Astacine carotin-oids
			Chlorophyll			Carotin-oids	Total	
			-a	-b	-c			
41°39'N 175°06'W	1335	.839	.9602	.7037	4.5461	-.2883	5.9217	.7423
20M	1335	.642	.9180	.1197	.6791	.2955	2.0123	.1302
41°43'N 175°09'W	1422	.956 .692	.2834	.1976	.8097	-.1949	1.0958	.4468
20M	1422	.746	.5047	.1653	1.0612	-.0180	1.7132	.2848
41°50'N 175°15'W	1555	.700	1.0490	1.0838	5.9148	-.4103	7.6373	.7940
20M	1555	.856	1.3774	.9094	5.4583	-.2870	7.4581	.7927
41°52'N 175°08'W	2020	.310	3.6271	2.7616	22.3919	-1.4828	27.2978	2.5935
41°28'N 175°10'W	0812	.771	1.1945	.8601	6.5217	-.3944	8.1819	.8116
20M	0812	.947	.1421	.1188	.7526	-.0344	.9791	.2247
40°29'N 175°11'W	1920	.189	.6773	.3390	3.1946	-.1693	4.0416	.4394
38°52'N 175°06'W	0820	.311	.5029	.8098	3.5460	-.2975	4.5612	.5861
20M	0820	.140 .015	.6603	.1265	4.6530	-.2123	5.2275	.5510
38°07'N 174°34'W	1552	.104 .310	.5581	.4865	2.7216	-.0085	3.7577	.3784
Carboy 3	1555	.080	1.7689	1.6235	11.6117	.7931	15.7972	1.4550
38°28'N 173°43'W	2010	.102	.5719	.1871	3.2239	-.3526	3.6303	.8170
Carboy 3	2005	.018	.1132	.3580	.7086	.0531	1.2329	.1882
38°45'N 173°04'W Carboy 3	2350	.032	.5165	.4318	2.7357	-.2405	3.4435	.5299

Station	Time of sampling	Mg C/ hr./m.^{3}	Photosynthetic pigments					Astacine carotinoids
			Chlorophyll			Carotinoids	Total	
			-a	-b	-c			
39°18'N 171°32.5'W	0800	.332	.5452	.5199	2.1339	-.1439	3.0551	.3874
20M	0800	.350	.2518	.2495	1.5467	-.0961	1.9519	.2946
39°50'N 170°52'W	1940	.156 .242	1.4479	1.4694	6.4536	-.4770	8.8939	.9604
40°03'N 170°42'W 20M	0820	1.102	1.1669	.9541	6.4297	-.3707	8.1800	.7748
40°15'N 170°16'W	1950	.048	.6996	.2979	3.8976	-.4545	4.4406	.7246
40°15'N 170°16'W	0830	.640	.7201	.6914	2.7636	-.0374	4.1377	.3972
4M	0830	.418	1.5867	1.5135	7.7347	-.8597	9.9752	1.4447
9M	0830- 0900	.305	.0401	.1530	.9350	.1284	1.2565	.1365
40M	0830- 0845	.383	.8252	.1382	2.7879	-.5040	3.2473	.6558
62M	0830- 0900	.202	.1576	.0906	.6105	-.1730	.6857	.2579
40°58'N 170°16'W	2025	.221	.9508	.7832	3.4475	-.2236	4.9579	.5504
41°26'N 170°38'W	0840	.346 .607	.3855	.5224	1.8008	-.1116	2.5971	.2579
20M	0840	1.141 .823	.6573	.5072	3.2513	-.1254	4.2904	.5101
42°21'N 170°12'W	2000	.290	.2777	.0649	-.3974	.2035	.1487	.0062
42°21'N 170°12'W	0835	.886				.2126	.2126	.1906
3M	0840	.777	1.0082	.7001	4.0752	-.1358	5.6477	.6043
14M	0850	.754	.3328	.0718	.6304	-.1450	.8900	.6106

Station	Time of sampling	Mg C/ hr./m.^{3}	Photosynthetic pigments					Astacine carotin-oids
			Chlorophyll -a	Chlorophyll -b	Chlorophyll -c	Carotin-oids	Total	
24M	0855	.839	.3422	.2269	1.4898	.0545	2.1134	.2237
30M	0835- 0915	.344 .208	.1445	.1734	.1456	.3007	.7642	-.0545
42°47'N 169°57'W	2007	.348	.3278	.0564	.5491	.0749	1.0082	.2130
42°56'N 169°56'W	0825	.930	.4939	.8197	.7742	-.1662	1.9216	.5022
20M	0825	.717	.2013	-.1999	1.3124	.1771	1.4909	.2206
44°05'N 169°21'W	2020	,283 .492	.4761	.5475	.7636	-.0166	1.7706	.3132
44°40.5'N 168°35'W	0912	.671	1.6588	1.2650	9.2219	-1.1854	10.9603	1.4005
45°46'N 168°46'W	1920	.429	.6628	.1544	2.4451	-.1133	3.1490	.4116
45°58'N 166°16'W	0820	.972	.5212	.4150	3.0040	-.1077	3.8325	.2930
20M	0820	.957	.4212	.5688	-.3168	.2349	.9081	.0567
46°34'N 164°47'W	1955	.296	1.6486	1.3537	8.0823	-.4699	10.6147	1.0768
46°34'N 164°28'W	0930	.550	.6545	.6444	2.3230	.0325	3.6544	.3458
3M	0905	.525	.4107	.1865	.2906	.1863	1.0741	.0600
7M	0910	.582	.6748	.4628	1.6426	.0755	2.8557	.2473
14M	0915	.562	.2778	.2322	1.4713	.1502	2.1315	.0942
23M	0920	.281	.4416	.2225	-.7774	.1707	.0574	.0811
30M	0905- 0930	.214	.6072	.4930	4.2620	-.1531	5.2091	.5135
45°52'N 164°37'W	2005	.335	1.1575	.7093	4.1700	-.1381	5.8987	.5108

Station	Time of sampling	Mg C/ hr./m.^{3}	Photosynthetic pigments					Astacine carotinoids
			Chlorophyll			Carotinoids	Total	
			-a	-b	-c			
44°58'N 165°06'W	0835	1.020	.6211	.2563	1.8556	-.4760	2.2570	1.3021
20M	0835	1.172	1.0738	.2688	6.2362	-.2964	7.2824	.7728
42°09.5'N 163°48'W	0757	.922	.3448	.2284	.9906	.0933	1.6571	.1964
40°26.5'N 163°35.5'W	1958	.262	.9040	.8520	3.6560	-.2984	5.1136	.6350
38°23.5'N 163°20'W	0800	.561 .806	1.5440	.8894	6.3445	-.5588	8.2191	.9059
36°20'N 162°50'W	2000	.102	.4682	.3912	2.4796	-.2711	3.0679	.4264
34°48.5'N 162°12.5'W	0800	.438	.2317	.1937	1.2272	.3629	2.0155	.0427
31°04'N 160°49'W	0800	.156	.5800	.4840	.5313	-.0743	1.5210	.4211
29°05.5'N 160°20'W	2000	-.028	1.9419	1.8155	11.0323	-.8396	13.9501	1.4169
27°02.5'N 159°45.5'W	0800	.165	.2293	.1206	1.2618	-.0560	1.5557	.2522
25°14'N 159°06'W	2000	.023	.0519	.0017	.7645	-.0448	.7733	.1040
23°18'N 158°35'W	0800	.118	.3574	.2102	.2033	.1616	.9325	.1072
20M	0815	.649	.9426	.2330	4.3431	-.1164	5.4023	.3829

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Introduction of the Marquesan Sardine, *Harengula vittata* (Cuvier and Valenciennes), to Hawaiian Waters

GARTH I. MURPHY[1]

PROGRAM of introduction of the Marquesan rdine was undertaken by the Bureau of Com- ercial Fisheries, Hawaii Area, at the request of e Hawaii Division of Fish and Game. The ob- ective was to introduce a species of fish to the awaiian Islands that would be suitable as na bait in order to supplement the somewhat nuous supply of the nehu, *Stolephorus pur- ureus* Fowler. The stimulus for the request and e subsequent program stemmed from the fact at the fish fauna of the Hawaiian Islands is otable for the number of endemic species and e absence of many forms that are common in e central Pacific islands to the south. Gosline 1955) proposed that the migration route of ore fishes to Hawaii is from the south and at Johnston Island, some 600 miles south of e Hawaiian chain, is the stepping stone. He ggests that the failure of many forms to reach awaii can be attributed to the large over-water stance to be traversed in crossing first to John- on Island and then to Hawaii, to possible ological screening of fishes at Johnston Island, d finally to the possibility that the Hawaiian lands do not offer the necessary habitat for rtain of the absent forms, especially in regard species missing in Hawaii but found at John- on Island.

The Marquesan sardine was first recorded as na bait by Royce (1954), who found them to abundant and accessible in the Marquesas and itable for tuna fishing. Additional factors sug- sted that they would be a useful and success- l species in Hawaii. They were found along e surf line in the Marquesas but generally ong rocky, sandy, sheltered beaches, a habitat t usually frequented by the nehu. (Thus, it d not seem likely that they would compete di- ctly with the nehu.) The Marquesas are high, lcanic islands as are the Hawaiian Islands and, with the exception of the scarcity of coral in the Marquesas, appear to represent the same general type of environment as the Hawaiian Islands.

Negative factors relative to the introduction are the somewhat cooler water temperatures in Hawaii and the fact that our seasons are reversed.

Ordinarily, such an expensive project as transferring a marine fish from 10° south of the Equator to 20° north of the Equator would not be undertaken without an extensive investigation of the fish's life history to evaluate the chances of successful introduction and to weigh thoroughly the possibility that the species might do harm in the new area. The possibility of harm seemed remote, and the expense not critical because a program of introduction could be incorporated in an investigation of the Marquesas area by the Pacific Oceanic Fishery Investigations (now known as the Bureau of Commercial Fisheries, Hawaii Area).

The several releases in Hawaiian waters (Table 1) were made as close to shore as operationally feasible and in habitat situations that were regarded as suitable for the Marquesan sardine. Examination of the gonads of the sardines in Marquesas waters suggested that nearly all of the individuals brought to Hawaii were young, mature adults.

In lieu of an extensive recovery program, wide publicity was given to the releases and a special poster, which included a photograph of the sardine, was widely distributed throughout Hawaii wherever fishermen were likely to congregate. The poster was especially directed to tuna fishermen because they use fine mesh nets when fishing for the nehu. Relying primarily on tuna fishermen for recoveries has several obvious advantages and one serious disadvantage, for one would expect that the Marquesan sardine would not be most abundant in the same habitat as the nehu.

It is not the purpose of this discussion to

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[1] Fishery Research Biologist, Bureau of Commercial heries, Hawaii Area, Honolulu, Hawaii. Manuscript eived November 17, 1958.

TABLE 1

RECORDS OF THE MARQUESAN SARDINE (*Harengula vittata*) IN HAWAIIAN WATERS

RELEASES				RECOVERIES			
Date	Locality	Estimated number	Fork length (mm.) range and mean	Date	Locality	Number	Fork length (mm.) range and mean
12–17–55	Barbers Point, Oahu	11,000	66–115 (88)				
9–26–56	Hanauma Bay, Oahu	7,000	76–127 (101)				
				9–27–56	Kalihi Channel, Oahu	1	106
3–22–57	Pokai Bay, Oahu	27,000	78–116 (94)				
				3–26–57	Kaneohe Bay, Oahu	1	90
				3–27–57	Kalihi Channel, Oahu	1	90
				4– 8–57	Kaneohe Bay, Oahu	4	87–93 (91)
				6– 4–57	Kaneohe Bay, Oahu	1	103
				9– 9–57	Barbers Point, Oahu	6	120–145 (134
12–14–57	Ewa, Oahu	31,000	90–111 (99)				
2–25–58	Ewa, Oahu	53,000	72–123 (98)				
				2–28–58	Honolulu Harbor, Oahu	4	82–101 (92)
				4–29–58	Pearl Harbor, Oahu	3	108–114 (111
5– 2–58	Ewa, Oahu	8,000	47–134 (102)				
6–23–58	Maunalua Bay, Oahu	3,000	84–115 (101)				
				6–27–58	Honolulu Harbor, Oahu	1	102
				6–30–58	Kaneohe Bay, Oahu	1	105
				7– 5–58	Kihei, Maui	10	Not examined
				9–10–58	Port Allen, Kauai	6	67–72 (70)
				9–23–58	Kaneohe Bay, Oahu	1	62
				9–25–58	Hanalei Bay, Kauai	6	74–84 (80)
				10– 2–58	Port Allen, Kauai	6	43–84 (71)
				10– 7–58	Kihei, Maui	29	37–61 (52)

evaluate the program completely to date; the passage of time will furnish definitive information in this respect. The pattern of recoveries in Table 1 however does permit optimism. The first release yielded no recoveries and the second was followed the next day by a single recovery. There were no additional recoveries until a fe days after the next release on March 22, 195 about six months later. It is significant that th planting was nearly three times as large as i predecessors and was followed by a number recoveries culminating in the capture of s rge adults off Barbers Point by a fisherman, sing a gill net. This recapture was significant ecause (1) the fish recaptured were larger than y planted in Hawaiian waters (in fact the rgest were longer than any measured in Mar- esan waters), and (2) examination of the ecimens suggested that they were very close spawning. There were no additional recov- ies for another six months and these followed ose on the heels of an additional release, as d the two recoveries in June, 1958.

In July, September, and October, 1958, there ere recoveries that did not fall into the usual ttern. First, the sardine was reported from auai and Maui where they had not been anted, and, perhaps more significant, some of e specimens were very small in size, strongly ggesting that there had been successful re- oduction.

Of 1,300 fish measured in the Marquesas dur- g the spring of 1958, only 81 were smaller an 75 millimeters. Considering only the last o stockings, only 3 of 50 fish measured were s than 75 millimeters and these were planted May of 1958. For these small specimens to ve originated from the stockings would re- ire both that the fish did not grow during eir three or four months' stay in Hawaii, and that there was a highly improbable statistical accident. In view of the growth evinced by the six specimens taken off Barbers Point on September 9, 1957, this seems remote.

In summary, substantial numbers of Marquesan sardines have been released in Hawaiian waters; there have been numerous casual recoveries by commercial fishermen in Hawaii, all indicating that the individuals released were healthy. Finally, there is now at hand good evidence that the species has spawned. To the writer's knowledge, this is the first successful introduction of a purely marine fish species; perhaps the success is not unexpected because of the general impoverishment of the Hawaiian marine fauna and the attendant vacant niches. This type of faunal impoverishment has generally been the basis of the numerous successful fresh water introductions of exotic fishes.

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outh of the countercurrent, the temperature of the aters above the thermocline were generally 74° to 0°F. In contrast, along the December 1957 section, mperatures in the surface layer, from 12°N. to at ast 8°S. latitude were 80°F. or above, reaching a aximum value of 83.8°F. in the countercurrent. he 80°F. isotherm reached depths of 500 feet or ore near the Equator. From consideration of surface mperatures at Christmas Island, figure 38, the means r early October and for December 1957 were 3°F. d 6°F. warmer, respectively, than the same months, 955. From consideration of the subsurface distribu- on (Fig. 39) the subsurface temperature conditions ere very similar during September 1955 and early ctober 1957, not clearly reflecting the apparent arming, while in a similar consideration of the two ections for December 1955 and 1957, figure 40, the urface and subsurface differences are strikingly vident.

If we compare the October and December 1957 sec- ions (shaded areas and solid curves, figures 39 and 0, at least two interesting points may be seen. First, ithin approximately 90 days, a large quantity of arm water had apparently moved into the area, too arge a quantity to be attributable to local effects uch as that of insolation. In general, with persistent outheast trades, advection through 150°W. by the esterly South Equatorial Current would transport oler waters normally found to the east of 150°W. pwelling would cool the surface waters near the quator. This situation, as inferred from variations in epth of the 60°F. and 70°F. isotherms, is illustrated n both the December 1955 and the October 1955 sec- ons. These isotherms reach a maximal depth near °N., decreasing in depth toward the Equator, then ncreasing again in the Southern Hemisphere. The re- ulting ridge centered near the Equator reflects both esterly transport and upwelling. However, in the ecember 1957 section (Fig. 40), the same isotherms eepen continuously, 5°N. to the Equator, then slope pwards in the Southern Hemisphere. The trough thus ormed near the Equator suggests, in contrast to the tuation for December 1955 and October 1957, east- rly transport through 150°W. of the warmer surface waters from the west and little or no upwelling. That such transport may have been the case is supported by an observation of a 5-knot easterly set, 00°30′N. to 02°30′N.; 160°W. reported by the SS *Monterey* on November 25, 1957.

Available data are too few to permit any more than speculation as to what processes may have been involved in causing these variations between the October and the December meridional, temperature-depth distributions. In general terms, there is a progressive east-west warming of the surface waters in the Equatorial Pacific, with the most pronounced east-west gradient to be found east of the 180th meridian. The sea surface in the Western Pacific is 0.8 to 1.0 dynamic meters higher than in the east; the thermocline progressively shallows, west to east. The existence of and variations in these situations are related to the presence of and variations in the trade wind system.

We mentioned above that vertical distribution of temperature for the October BT section suggested westerly flow of the surface waters, 5°N. to the southern limit of the section and upwelling centered about the Equator. This is the ''normal'' situation with the easterly component of the trades. With a relaxation of the trades, and particularly with a comparatively high frequency of westerlies, one could postulate a reversal in flow of the surface waters (and the undercurrent reaching the surface), with the warmer waters from the west becoming evident through the 150°W. section. A second factor leading to warmer waters in the surface layers—westerly winds are *convergent* in terms of surface flow at the Equator, thus there would be no divergence of the surface waters and no upwelling of the deeper, cooler waters. From advance indications of the available data, this may have been the situation during the December 1957 section.

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THE OCEANOGRAPHIC SITUATION IN THE VICINITY OF THE HAWAIIAN ISLANDS DURING 1957 WITH COMPARISONS WITH OTHER YEARS

GARTH I. MURPHY, KENNETH D. WALDRON and GUNTER R. SECKEL
Pacific Oceanic Fishery Investigations

During the past three years POFI initiated a number of temperature and salinity monitoring stations in the Central Pacific as follows: Oahu, Hawaii; Johnston Island; French Frigate Shoals; Midway Island; Wake Island; Christmas Island; and Weather Station "Victor." The purpose of this network is to develop time series that can be related to variations in the oceanic circulation which, we anticipate, can in turn be related to variations in the distribution of skipjack and other tunas. At the present only the Christmas Island and Oahu stations have been established long enough to provide material suitable for discussion. The Christmas Island station is reported on elsewhere, leaving the Oahu station and other pertinent observations in the vicinity of Hawaii for consideration here.

SURFACE TEMPERATURE AND SALINITY AT OAHU

The Koko Head station is occupied each Tuesday morning about 9 a.m. A bucket of water is dipped from the cliff, temperature measured and the salinity sample returned to the laboratory for titration. There are no coral reefs at the station; the depth drops off abruptly to about thirty feet below the cliff and then quickly falls off to deep water. There are no nearby streams either, and thus the location is close to ideal with respect to non-interference of shallow water warming and run-off. Offshore surveys conducted simultaneously with the shoreside observations give us further confidence that water samples taken there are representative of general conditions off that portion of Oahu.

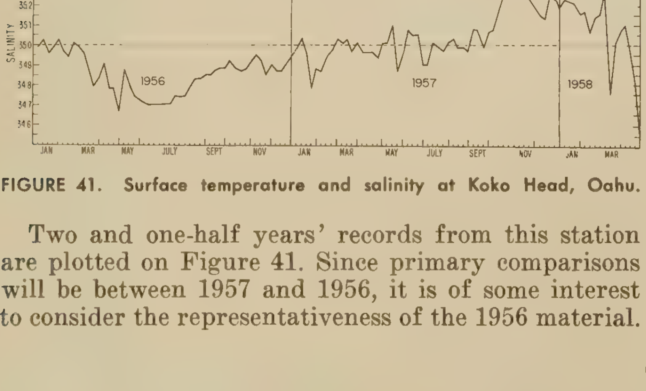


FIGURE 41. Surface temperature and salinity at Koko Head, Oahu.

Two and one-half years' records from this station are plotted on Figure 41. Since primary comparisons will be between 1957 and 1956, it is of some interest to consider the representativeness of the 1956 material. Though not herein documented, our accumulation records suggests that 1956 was very close to an avera year with respect to temperature and with respect salinity. Weather patterns and biological patter were also reasonably representative of average cond tions during that year. We can then with some con dence treat 1956 as a base and proceed with inte comparisons between 1956 and 1957.

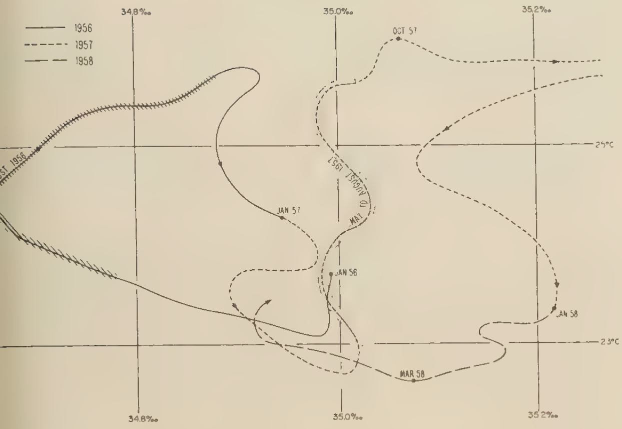
With respect to surface temperature, the pattern 1957 was similar to 1956 insofar as maximum a minimum temperatures are concerned. However, it clear that spring warming was accelerated in 1957 a the winter cooling was also more accelerated. The data in themselves are not clear evidence of a signi cant change in the advection pattern.

Surface salinity (Fig. 41) shows 1957 to be mar edly different from 1956. The March-May decline salinity followed by a gradual rise in salinity fro about the first of July onward did not occur in 195 Instead, salinity in 1957 remained almost consta until mid-September when it rose abruptly to leve higher than those ever recorded. This was followed the spring of 1958 by an abrupt decline to what mig be regarded as normal spring salinities. The decli however was short-lived, and during the first week April salinities again rose to about $35.0^0/_{00}$ and r mained at that level, at least through the third we in May (not included in plot on Fig. 41).

The major trends in the salinity data can only accounted for by advection; for instance, the Marc May decline illustrated by 1956 occurs at a time decreasing rainfall. Each of the other major tren illustrated either were contrary to what might ha been expected from rainfall and isolation, or cou not be accounted for by these factors. However, least some of the short-term changes in salinity ca be correlated with rainfall, the most graphic examp being the mid-March, 1958 decline; this occurred c incidental with a rainfall of about two feet within 24-hour period.

From the data on figure 41 we can safely conclu that there are seasonal changes in advection in t vicinity of the Hawaiian Islands and that the typic seasonal changes did not occur in 1957; rather, t island area was brought under the influence of wat masses that do not normally influence the area.

The data on figure 41 replotted in smooth form o figure 42, graphically illustrate the difference betwe the two years. The treatment on figure 42 is in essen a T/S curve, time being the third and non-linear var able, rather than depth. It is interesting to note th many features of the basic pattern were similar duri the two years, very possibly reflecting similar patter



URE 42. Surface temperature and salinity at Koko Head, Oahu (data smoothed by eye).

temperature and rainfall between the two years. any details are, however, different between the years d it is clear that the basic temperature-salinity relanship was very dissimilar between the two years.

In summary, the normal seasonal pattern in Hawaii volves high salinity and low temperatures in Ocber-February, and low salinity and high temperares during the summer. In 1957 the temperature gime resembled the normal except that the rates of crease and decrease associated with the Septembertober maximum were greater. In 1957 the salinity gime was very different from normal. The May-July w salinity did not develop and the ensuing winter w salinities rise to higher than normal levels. The gime for 1958 has not clearly established itself. ese differences in salinity and temperature can only explained on the basis of changes in advection ttern in the island area.

STRIBUTION OF SALINITY NORTH ND SOUTH OF OAHU

One of the authors (Seckel) is in the process of mmarizing and analyzing all available oceanogric data from the portion of the Central Pacific tlined in figure 43. This chart depicting certain rface isopleths shows that the mean position of the .0 isopleth during the period, April to July, is about degrees north of Oahu. During the contrasting sea, November to February, this isopleth lies about ree degrees south of Oahu. This migration is quite mpatible with the results of the salinity changes th time at Koko Head during 1956, which we believe be close to an average year but is quite dissimilar om 1957.

A north-south profile of surface salinities during 57 (April to July) figure 44 shows the 35.0 isoth to be almost coincidental with the latitude of hu, rather than 2½ degrees north of Oahu, Interestgly enough, the surface salinities that should have evailed during 1957 at Oahu were located almost actly 2½ degrees south of Oahu. Figures 43 and 44 ggest that the normal spring north-south profile of rface salinity had about the same shape in 1957 and 1956, but was simply displaced about 2½ degrees south in 1957.

The sum total of our observations suggest that normally during the winter the vicinity of Hawaii is under the influence of cool, high-salinity water of northern origin. Normally during the summer this high-salinity water seems to be displaced to the northward and the islands are influenced by lower-salinity, warm water that possibly originates to the southeast. Perhaps the high-salinity water is downstream, or is influenced by downstream Kuroshio flow, and signals advection from the west. During March-May this easterly-flowing water is displaced to the north and tends to be replaced by lower-salinity water from the southeast. Perhaps the water is related to California Current water. In 1957 this warm, low-salinity water persisted through spring, summer and the subsequent winter.

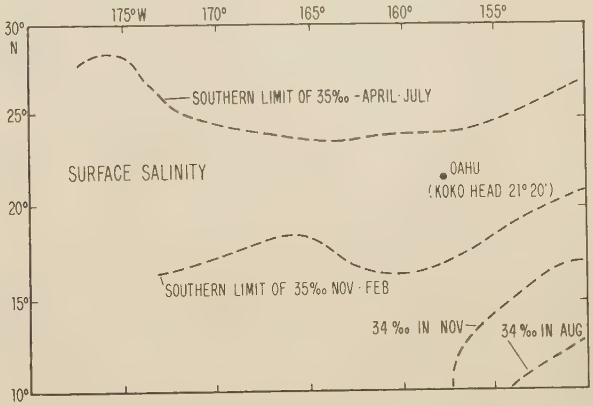


FIGURE 43. Mean Seasonal Locations of 35⁰/₀₀ and 34⁰/₀₀ Isopleths (Approximately 700 surface observations 1957 data not included).

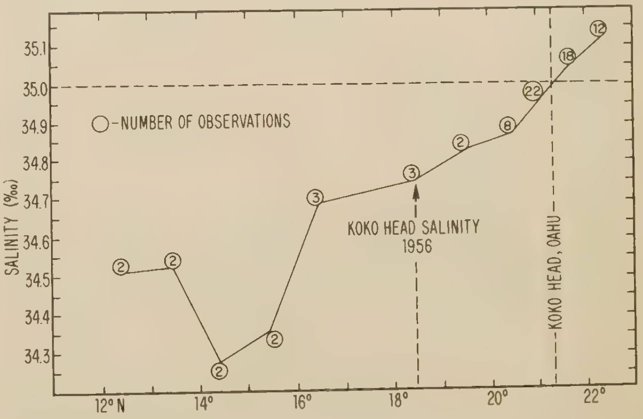


FIGURE 44. Mean surface salinity by latitude at the longitude of Oahu during the period April to July 1957.

SKIPJACK

The skipjack season in Hawaii undergoes marked seasonal, as well as annual variations. Though the annual variations may be large, they have not during any year of record been great enough to suppress the seasonal pattern. July is almost invariably the peak month and December, January and February are almost invariably low points in the annual cycle. Typically, landings begin to rise in April, rise precipitously in May and June, peak in July, and fall off fairly precipitously to October. Variations in effect may serve to accentuate the peaks and valleys, but by and large effort is constant throughout the year so the catch must be interpreted in terms of immigration and emigration of fish through the Hawaiian region. (The Hawaiian tuna fishery generally operates within 20 miles of land so that fishery is in effect a point fishery, unlike the Southern California tuna fishery, which roams over a vast expanse of ocean.) In addition to the seasonal shift in the magnitude of the catches there is a change in the size composition with winter or off-season catches generally comprised of small individuals, five to ten pounds in weight, and the bulk of the season or summer catches comprised of large individuals ranging from 15 to 25 pounds in weight. This change in the composition of the fishery lends further weight to the assertion that the basic changes in landings are functions of the movements of the fishes rather than changes in effort or economic factors.

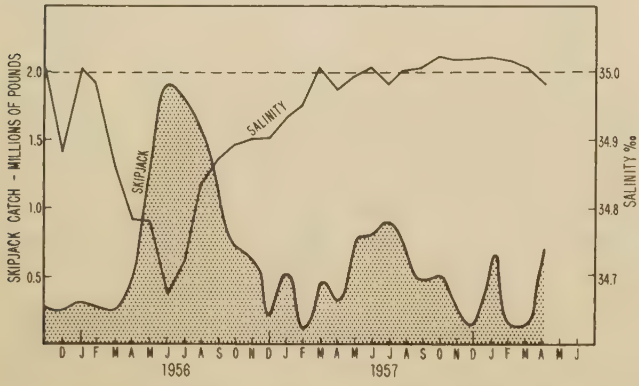


FIGURE 45. Monthly Skipjack landings and mean monthly salinity at Koko Head.

There is now a substantial body of evidence that shows the development of the season, that is the immigration of skipjack to Hawaii is related to the impingement of the warmer, less saline waters from the southeast into the island area. The first indication we had of this came in 1956 from a comparison of our Koko Head monitoring records and the skipjack landings. These data are shown on figure 45, together with similar data from 1957. As already demonstrated, and again indicated on figure 45, the low-salinity water did not impinge on the islands in 1957, and this is associated with failure of the fishery in 1957. The 1957 catches also differed from the 1956 catches in respect to size of fish; the large 15 to 25 pounders were almost entirely absent, the fishery being supported by smaller, typical winter skipjack. This sequence of events led us to examine the catches, that is the summer catches, during earlier years together with such records on salinity as we could assemble. These are tabulated below. It is clear from these figures that, at least during the five years' records, good or average

season catches were associated with the presence
lower salinity water while poor catches, including t
lowest on record since the war, were associated wi
higher salinity water.

$< 35.0\ {}^{0}/_{00}$	$> 35.0\ {}^{0}/_{00}$
1951—9.9 million lbs.	1952—4.8 million lbs.
1953—7.1 million lbs.	1957—3.2 million lbs.
1956—7.2 million lbs.	

If the skipjack are actually associated with lo
salinity water, this association should be particular
sensitive during the spring, that is April and Ma
when the fishing season is just developing. Figure

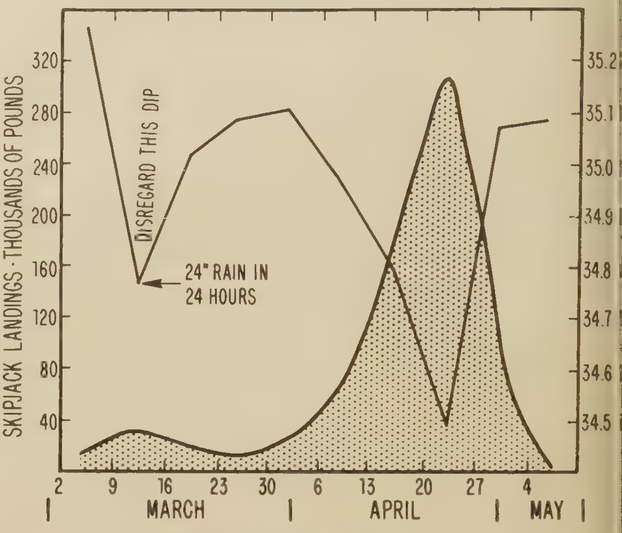


FIGURE 46. Spring of 1958. Weekly Skipjack landings and wee
salinities, Koko Head, Oahu.

illustrates the weekly records for the spring of 19
during which time the ocean apparently formed
neat experiment for us. As may be seen salinities f
to an extraordinarily low level during the last we
in April and this was exactly coincidental with
marked upsurge in skipjack landings; in fact, t
rate of landings during the peak week was quite hi
for April and coincides with a typical June-Ju
week's landings during the normal season. Followi
this, salinities rose abruptly to winter levels and t
catch dropped to winter levels.

If the immigration of skipjack is associated wi
the advection of low-salinity water from the sout
east, there should be corresponding evidence of dire
tional movement of the fish. Data are available fro
two sources: (1) the pattern of landings along t
island chain with the advance in the season and (
the results of tagging. Unfortunately for a variety
reasons, the data from both of these sources do n
provide a critical evaluation of the direction of mov
ment of the skipjack. However, there are several ind
cations that the fish do move into the island area fro
the southeast and no contradictory indications.

If we assemble all of this information into juxt
position, it is possible to erect a relatively sim
hypothesis to account for seasonal variations in ski
jack landings in Hawaii, as follows. The skipjack th

ter the Hawaiian fishery are a portion of a popula-
n migrating from east to west in a body of low-
linity water suggestive of downstream California
rrent water. If this low-salinity water impinges on
e island area, skipjack in large numbers appear
the island fishery. The season is terminated either
the passage of the last wave of migrant fish, or
nply by retreat of the low-salinity water, or both.
e migration of skipjack entering the island area
ay be disrupted and delayed in response to special
eding situations that they encounter. This hypoth-
is relegates the islands to the role of an operating
se for the fleet, rather than a base for the skipjack,
d is in accord with our failure to find significant seasonal differences in the standing crop of biota in the Hawaiian Islands and our observation that during a typical season skipjack are abundant far south of the islands, well beyond the possible influence of the islands, whereas indications are that they are not abundant very far to the north of Hawaii. The problem of change in size of the skipjack with the onset of a typical season is also susceptible to explanation for many populations of tuna to arrange themselves geographically by size, the most typical picture being the small fish in a population tending to dominate the extremities of the environment. If we interject this additional factor, we can understand the absence of large fish during the 1957 ''season.''

ADVECTION—A CLIMATIC CHARACTER IN THE MID-PACIFIC

GUNTER R. SECKEL
Pacific Oceanic Fishery Investigations

In an attempt to discover oceanographic changes in the Hawaiian Islands region which may be associated with the seasonal nature of the skipjack fishery and its annual fluctuations, we have been looking into what might be described as the "oceanographic climate" of the region. This involves a study of the time and space distribution of surface variables which by means of budget considerations will yield some information regarding the processes associated with these distributions. The following notes describe partial results of this study and may be of interest during the second portion of this Symposium.

Since the temperature is of primary interest in any climatic study, the following will deal with the heat budget of the surface layer. On the basis of conservation of heat one can say that at any locality in the ocean the net heat exchange across the sea surface must be balanced by the change in heat content of the water column, heat diffused through the sides of the column, and the heat carried in or out of the column by means of currents. Such an expression can become rather complicated. However, since this is to be a climatic study, interest lies with the gross seasonal changes and therefore some simplifying assumptions can be made for the Hawaiian survey region (10°-30°N., 150°W-180°).

In this area the mixed surface layer is generally well defined and since it has neutral stability one can say that heat exchanged across the sea surface is uniformly distributed throughout this layer. Furthermore, because of high stability in the thermocline just below the mixed layer, and small horizontal temperature gradients, vertical and lateral diffusion are assumed negligibly small compared to advection and heat exchange across the sea surface. With these assumptions the heat budget and the volume budget of a column of water of unit cross sectional area can be expressed by

$$\frac{\partial z}{\partial t} = -\nabla(z\bar{v}) \text{ and } \frac{\partial(C_p z\theta)}{\partial t} = H - \nabla(C_p z\theta\bar{v})$$

which after expanding and combining reduce to

$$\frac{\partial\theta}{\partial t} = \frac{H}{zC_p} - \bar{v}\cdot\nabla\theta$$

In the above equations H is the net heat exchange across the sea surface (insolation less evaporation less back radiation less conduction), θ is the surface temperature, C_p is the specific heat at constant pressure which can here be considered constant, z the depth of mixed layer, $\bar{v}$ the velocity, and ∇ the operator

$$\bar{i}\frac{\partial}{\partial x} + \bar{j}\frac{\partial}{\partial y}$$

The last equation, the temperature budget, state
that the time rate of change of temperature and not th
absolute temperature is of importance when process
are considered. The equation also points out that i
order to understand the advection term ($\bar{v}\cdot\nabla\theta$) th
horizontal distribution of temperature about the loca
ity of interest must be known. In other words, by know
ing the horizontal temperature gradient, one can obtai
a measure of the velocity component perpendicular t
the isotherms. Finally, heat advection cannot give an
information about the velocity component parallel t
the isotherms.

A similar expression for the salinity budget in th
surface layer is as follows:

$$\frac{\partial s}{\partial t} = \frac{s}{z}(E-P) - \bar{v}\cdot\nabla s$$

Here s is the salinity and $(E-P)$ the evaporatio
minus precipitation.

The above discussion as well as the approximat
values of $\frac{\partial\theta}{\partial t}$ and $\frac{H}{zC_p}$ used below, will be presente
with more detail in the climatic atlas which is in prep
aration for publication.

Of interest now are the graphs obtained when $\frac{\partial\theta}{\partial t}$
and $\frac{H}{zC_p}$ are plotted versus time as shown in figur
47A. The solid line shows the mean seasonal variatio
of the rate of change of surface temperature in th
vicinity of Oahu, Hawaii, and the dashed line th
seasonal rate of change of surface temperature due t
the net heat exchange across the sea surface only. Th
difference between the two curves indicates advection

Thus, when $\frac{H}{zC_p} > \frac{\partial\theta}{\partial t}$, the component of flow across
the isotherms is from cold to warm, indicating cold
advection. When $\frac{H}{zC_p} < \frac{\partial\theta}{\partial t}$, warm advection is indicated. No advection $\frac{H}{zC_p} = \frac{\partial\theta}{\partial t}$, indicates either
flow parallel to the isotherms or no flow.

Figure 47A shows what may be called characteristic
advection features for the vicinity of Oahu: low advection from February to May, and considerable advectio
for the remainder of the year.

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Thirty-fifth Annual Meeting, 1959-60.
Published by the University of Hawaii, Honolulu, Hawaii, 1960.

4. CONFINEMENT OF SKIPJACK IN A POND[1]

e skipjack tuna (*Katsuwonus pelamis*), locally n as aku, is the most important commercial fish Iawaii. This species of tuna, which is distributed ughout the warmer seas of the world, represents source of protein capable of a much greater yield the amount presently being harvested. One phase e research at the Honolulu Biological Laboratory e development of more efficient methods of harvest- this resource. Clues for the development of such ods are being sought through investigations of ack behavior.

e part of the behavior investigations is the study kipjack responses to various stimuli. A requisite this study is the control of environmental condi- s of the test fish. Such control can be achieved with captive skipjack maintained in tanks or s.

pond, 23 feet in diameter and 4 feet deep, was lled at Kewalo Basin. This circular pond was l with water from an adjacent salt water well. water is less saline and more acidic than open a water and practically devoid of oxygen. It xygenated by allowing it to cascade through an or of special design.

itial attempts to establish skipjack in this pond unsuccessful. The fish, which were caught at y the live-bait method, were transported to the pond in the live-bait wells of the "Charles H. Gilbert," research vessel of the HBL. The transfers from the sea to the bait wells and from the bait wells to the pond involved considerable amounts of manual handling of the fish. None of these fish survived for more than two days.

A new method was tried in February, 1960. Skipjack were captured at sea by the same method but from a commercial fishing vessel. Immediately after capture and while still suspended from the hook, the fish were lowered into a portable steel tank, 6 feet wide, 8 feet long, and 25 inches deep. At Kewalo Basin, the tank was lifted off the vessel and lowered into the pond. A hatch in the side of the portable tank was opened and the fish allowed to swim out.

Skipjack handled in this manner soon adapted to conditions of captivity and were successfully induced to feed on dead food. Five skipjack of about 3 pounds in size have been held in confinement for over 12 weeks and have been feeding daily on pieces of shrimp and squid.

EUGENE L. NAKAMURA
U. S. Bureau of Commercial Fisheries
Honolulu, Hawaii

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Albacore Migration and Growth in the North Pacific Ocean as Estimated from Tag Recoveries

TAMIO OTSU

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Albacore Migration and Growth in the North Pacific Ocean as Estimated from Tag Recoveries

TAMIO OTSU[1]

THE ALBACORE, *Germo alalunga* (Bonnaterre), is considered a choice tuna by Americans because of its excellent canning quality. It is fished by Americans along the Pacific coast of the United States and by the Japanese in North Pacific waters extending from the coast of Japan to about the 180th meridian. In recent years the Japanese have extended their albacore fishing grounds to tropical and subtropical waters of the Pacific and Indian oceans (Mimura, 1957; Van Campen[2]), and more recently, to Atlantic waters.

A tagging program was instituted by the Pacific Oceanic Fishery Investigations (POFI) [in 1959 it became the Bureau of Commercial Fisheries, Hawaii Area] as a part of an albacore research project being conducted under Public Laws 329 (80th Congress) and 466 (Saltonstall–Kennedy Act, 83rd Congress). Employing the California type-G "spaghetti" tag (Wilson, 1953) (Fig. 1), and to a limited extent, the POFI- developed dart tag (Yamashita and Waldron, 1958), tagging was conducted on albacore taken by POFI vessels on exploratory cruises to the North Pacific. Intensive albacore tagging has been conducted on the West Coast by the California Department of Fish and Game and data on some of their recoveries have been published (Blunt, 1954; Ganssle and Clemens, 1953). This report summarizes the tagging results obtained by POFI, and includes a preliminary analysis of albacore migration and growth.

ACKNOWLEDGMENTS

The success of a tagging program depends largely on the cooperation of the fishermen making the recoveries, their interest in the program, and the care with which they record and transmit data pertinent to each recovery. We extend our gratitude to the numerous commercial fishermen and research agencies, both in the United States and in Japan, who have rendered excellent cooperation in this respect.

The writer is indebted to Dr. Robert H. Riffenburgh of the University of Hawaii for guidance in the growth analysis.

ALBACORE TAG RELEASES

Between January, 1954, and August, 1957, a total of 1,201 albacore was tagged and released in the temperate North Pacific (Fig. 2). Included in the total are 270 albacore tagged in the Japanese live-bait fishing grounds in the spring of 1956 (Van Campen and Murphy, 1957). The remaining tag releases were made in the central and eastern North Pacific, and consisted of 855 fish taken by surface trolling and 76 taken by long-lining.

The size-frequency distribution of the tagged albacore is given in Figure 3. The 270 fish tagged off Japan are not included since they were not measured. Measurements were made, however, on samples of fish from each school in which tagging was conducted, and these indicated a relatively narrow size range of 60.4 cm. to 83.4 cm. in length. In addition to these, 94 troll-caught fish tagged off the California coast are not included since no measurements were recorded. The long-line gear accounted for a wide size range of fish (50 to 120 cm.) while surface trolling took fish up to 87 cm. in length (Fig. 3).

ALBACORE TAG RECOVERIES

As of September, 1958, 15 (1.2 per cent) of POFI's tag releases had been recovered (Table 1). Seven of the recoveries (Nos. 1, 2, 3, 8, 9,

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[1] Fishery Research Biologist, Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii Manuscript received December 11, 1958.

[2] Van Campen, W. G. MS. The Japanese summer albacore fishery. Submitted for publication as a research report.

TABLE 1
POFI ALBACORE TAG RECOVERIES

NO.	DATE TAGGED	POSITION OF RELEASE		DATE RECAPTURED	POSITION OF RECAPTURE		NET DISTANCE TRAVELLED (miles)	DAYS OUT
		Latitude	Longitude		Latitude	Longitude		
1	10/4/54	46° 30′ N.	159° 18′ W.	11/28/55	35° 45′ N.	157° 39′ E.	2,055	420
2	10/5/54	43° 31′ N.	161° 16′ W.	1/19/56	35° 23′ N.	141° 20′ E.	2,670	471
3	10/9/55	42° 16′ N.	147° 16′ W.	6/24/56	31° 54′ N.	158° 37′ E.	2,660	259
4	10/17/55	44° 55′ N.	144° 48′ W.	8/1/56	31° 21′ N.	117° 17′ W.	1,515	288
5	7/31/56	44° 31′ N.	174° 55′ W.	7/23/57	30° 08′ N.	119° 03′ W.	2,775	357
6	8/1/57	34° 49′ N.	121° 57′ W.	9/17/57	34° 49′ N.	121° 26′ W.	26	47
7	7/22/57	35° 43′ N.	122° 58′ W.	10/7/57	36° 24′ N.	123° 07′ W.	41	77
8	10/16/55	43° 40′ N.	144° 40′ W.	11/23/57	33° 22′ N.	174° 07′ E.	2,025	769
9	11/17/56	36° 44′ N.	127° 37′ W.	11/17/57	38° 08′ N.	174° 53′ E.	2,800	365
10	7/23/57	42° 20′ N.	127° 33′ W.	5/26/58	32° 15′ N.	144° 15′ E.	4,230	287
11*	7/22/57	47° 00′ N.	126° 18′ W.	6/10/58	33° 40′ N.	144° 00′ E.	4,300	323
12	7/16/57	44° 47′ N.	130° 04′ W.	7/11/58	30° 00′ N.†	118° 45′ W.†	1,035	360
13	7/16/57	44° 47′ N.	130° 04′ W.	8/22/58	32° 00′ N.†	122° 00′ W.†	860	402
14	11/14/56	38° 00′ N.	128° 25′ W.	8/23/58	32° 15′ N.	122° 30′ W.	455	647
15	11/21/56	35° 21′ N.	123° 57′ W.	7/21/58	34° 00′ N.	122° 10′ W.	130	607

* Fish No. 11 was marked with a POFI dart tag; all others with California "spaghetti" tags.
† Approximate position of recapture.

10, 11) were made by the Japanese in their summer live-bait and winter long-line fisheries, while the remaining 8 were made by Americans in the West Coast fishery.

With the exception of two American recoveries (Nos. 6 and 7) which were made within 47 and 77 days, respectively, of the date of release, the remaining 13 represented relatively long periods between release and recovery, ranging from 259 to 769 days. While all of these long-term recoveries provided valuable information on the movements of albacore in the North Pacific, complete data on growth were not obtained since information on several of the recoveries did not include length or weight measurements.

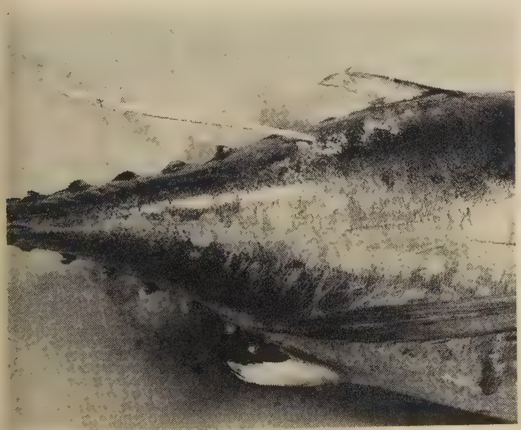

FIG. 1. An albacore (recovery No. 4) with a California type-G tag attached. This fish was at liberty for approximately 10 months before recapture (Table 1).

MOVEMENTS SHOWN BY TAGGED ALBACORE

The net movements of the tagged fish are depicted in Figure 4. Perhaps most significant is the migration of fish between the major fisheries. A fish tagged in the American fishery off California (No. 9) moved across into the Japanese mid-ocean winter long-line grounds to be retaken there. Two others tagged in the West Coast fishery off the Pacific northwest (Nos. 10, 11) made a complete trans-Pacific migration and were recaptured in the Japanese live-bait fishery. Albacore tagged in mid-ocean north of Hawaii migrated into the West Coast fishery (Nos. 4, 5) as well as into the Japanese long-line (Nos. 1, 2, 8) and live-bait (No. 3) fisheries. Tag recoveries reported by the California Department of Fish and Game also showed movements of albacore from waters off California to the coast of Japan (Ganssle and Clemens, 1953). Movement in the opposite direction, from the Japanese fishery into the American fishery, has yet to be demonstrated.

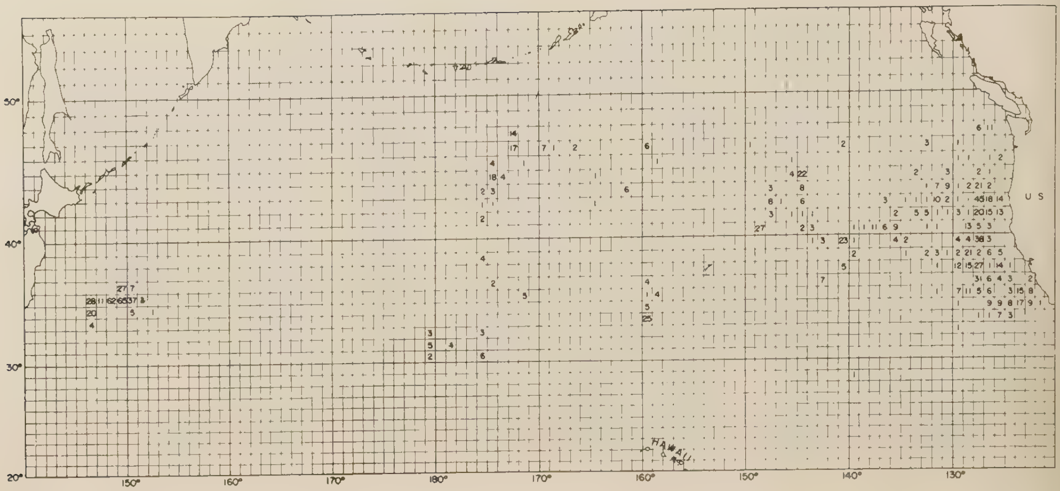

FIG. 2. Numbers and locations of POFI tag releases, January, 1954–August, 1957. (California type-G tag was used on 1,090, and the POFI dart tag on 111 albacore.)

GROWTH SHOWN BY THE TAGGED ALBACORE

Of 15 recoveries to date, 11 were accompanied by size data at the time of recovery (Table 2). The estimated annual growth of these fish was extremely variable, ranging from 3.8 to 28.7 cm. per year.

Although it is realized that the available data are inadequate for any conclusive growth study, a preliminary analysis was made in order to present some approximation of the albacore growth rate. Following the method of growth curve transformation described by Walford (1946), the length of fish at the time of release (age N) was plotted against the length after one year (age $N + 1$), the latter representing the length at release plus the estimated value of one year's growth (Fig. 5). There is a suggestion of linearity in the plots, with the exception of one (No. 2, Table 2). The growth reported for this fish is obviously out of proportion to the others. When the Japanese transmit data pertinent to a tag recovery they usually specify the method of measurement used. This was not done in this particular instance; for this reason and because the reported length seems excessive, this fish is dropped from further consideration. The remaining 12 points (including two from published California data) fall about the regression line $Y = 26.29 + .77867X$ obtained by the least squares method, where Y is the length at $N + 1$, and X the length at N.

Also shown in Figure 5 is the line of no growth ($L_N = L_{N+1}$) drawn in with a 45° slope through the origin. The point of intersection between the regression line and the line of no growth is described by Walford as the upper asymptote of the growth curve, which in this case falls at approximately 118 cm. The 118-cm. asymptote of maximum growth for the sample data of this paper is slightly less than that which would be expected for albacore populations in general; measurements of commercial landings indicate the population asymptote to be about 124 cm. (Suda, 1954; Otsu and Uchida, 1959*a*).

The growth curve (Fig. 6) was derived from Figure 5. This method does not enable us to obtain that portion of the growth curve falling below the point of inflection, and since the smallest fish for which there are data is a 60-cm. fish, the extrapolation toward the smaller sizes is dubious.

In an attempt to describe the complete growth curve, particularly that portion falling below the point of inflection, for which Walford's method does not apply, the data were fitted to a Gompertz equation, $y = ab^{c^{-x+d}}$, where y is the length in centimeters and x the age in years. A

TABLE 2
GROWTH SHOWN BY TAGGED ALBACORE

NO.	DATE OF RELEASE	DATE OF RECOVERY	DAYS OUT	SIZE AT RELEASE (cm.)	SIZE AT RECOVERY (cm.)	NET GAIN (cm.)	GAIN PER YEAR (cm.)
1	10/4/54	11/28/55	420	78.2	—	—	—
2	10/5/54	1/19/56	471	68.0	105.0	37.0	28.7
3	10/9/55	6/24/56	259	63.4	—	—	—
4	10/17/55	8/1/56	288	59.9	72.3	12.4	15.7
5	7/31/56	7/23/57	357	68.4	78.0	9.6	9.8
6	8/1/57	9/17/57	47	66.5	—	—	—
7	7/22/57	10/7/57	77	65.5	67.0	1.5	7.1
8	10/16/55	11/23/57	769	65.1	94.8	29.7	14.1
9	11/17/56	11/17/57	365	85.2	97.5	12.3	12.3
10	7/23/57	5/26/58	287	78.0	85.2	7.2	9.2
11	7/22/57	6/10/58	323	75.0	—	—	—
12	7/16/57	7/11/58	360	65.0	77.3	12.3	12.5
13	7/16/57	8/22/58	402	75.0	84.5	9.5	8.6
14	11/14/56	8/23/58	647	79.4	92.6	13.2	7.4
15	11/21/56	7/21/58	607	68.6	86.4	17.8	10.7
A*	8/11/53	2/2/54	176	84.0	88.0	4.0	8.3
B*	8/16/53	2/23/54	192	91.0	93.0	2.0	3.8

* Fish tagged by the California Department of Fish and Game and reported by Blunt (1954).

rapid approximation method by Riffenburgh[3] for estimating the parameters of the Gompertz curve was used. The same paper contains a lengthier and more precise method in which the estimates converge stochastically to the parameters, but it was felt that the number of data available was inadequate to assure convergence. Thus, the approximation technique was utilized.

The method uses three sets of data points: $(i,\ y_i)$, $(i+j,\ y_{i+j})$, and $(i+k,\ y_{i+k})$. The numerical calculation involved is markedly simplified if $k = 2j$. In this case, the triplet of points having x-values of $N + 3$, $N + 5$, and $N + 7$ (Fig. 6) was selected from among the set of triplets possessing the property $k = 2j$; these points fall approximately within the portion of the curve for which there are observed data. The corresponding y-values, obtained from Walford's curve, were $y_3 = 62.7$ cm., $y_5 = 84.8$ cm., and $y_7 = 98.2$ cm. The estimate of the parameter $c = 1.43$ was obtained by the equation:

$$c^{-j} = \frac{\log \dfrac{y_{i+k}}{y_{i+j}}}{\log \dfrac{y_{i+j}}{y_i}}$$

and the estimate of the parameter $b = 0.177$ by the equation:

$$\log b = \frac{\log \dfrac{y_{i+k}}{y_{i+j}}}{c^{-i}\ c^{-j}\ (c^{-j-1})}.$$

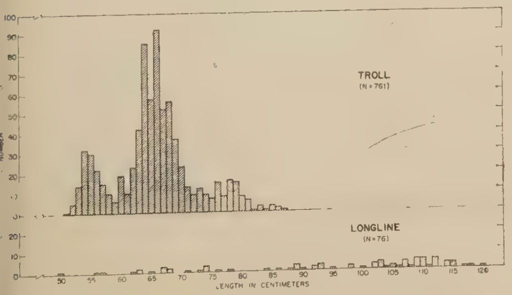

FIG. 3. Size-frequency distribution of albacore tagged by POFI in the North Pacific, January, 1954–August, 1957.

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[3] Riffenburgh, R. H. MS. A new method for estimating parameters of the Gompertz growth curve. University of Hawaii and Pacific Oceanic Fishery Investigation, U. S. Fish and Wildlife Service, Honolulu.

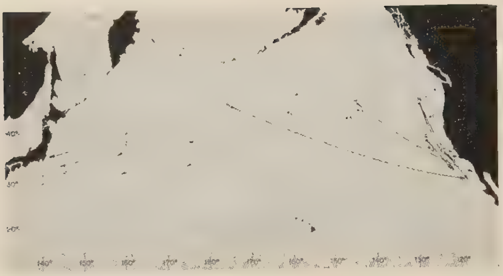

FIG. 4. Net movements of albacore tagged by POFI. (The lines have no significance other than connecting the points of release and recovery of each fish.)

The parameter *a,* or the upper asymptote of the growth curve (118 cm.), had already been estimated by Walford's method. These parameters were fitted into the Gompertz equation as follows:

$$y = (118)\ (0.177)^{(1.43)^{t+d}}$$

which resulted in the asymmetric sigmoid curve shown in Figure 7. Inspection showed that if this curve is shifted 0.23 year to the right, it will present an adequate fit for the data; thus, an estimate of *d* is 0.23.

The curve derived by the Walford method (Fig. 6) is superimposed on the Gompertz curve. There is fair agreement between the two in the portions representing lengths between 40 and 85 cm., and the observed data do not deviate much from either curve. If albacore growth follows a typical Gompertz curve, then this represents a possible entire growth curve of the albacore, including that portion not possible to determine by the Walford method. It should now be possible to assign specific ages.

It can be seen by inspection that the curve approaches the abscissa reasonably closely at *N* — 2 years, suggesting that hatching is in this time vicinity. While the size indicated at hatching deviates from the expected size to the order of 2 cm., this error is not large considering the assumedly random deviations of the observed data from the estimated growth curve and the small sample size. With *N* — 2 as the arbitrary origin, the adjusted ages are given below the original designations. The resulting length for each year beginning with this origin is presented in Table 3 along with values obtained by the Walford method. While there is every indication that at least a portion of each curve reliably represents the albacore growth, those portions for which there are no observed data should be considered tentative. The initial growth by the Gompertz curve appears to be unreasonably slow since it requires about 3 years for a fish to attain a weight of 1 pound (about 30 cm.). The early growth is slow, relative to the result obtained by the Walford method. The results suggest a possible error in assigned ages of 1 or 2 years.

This disagreement and others may result from one or a combination of the following debilities: (a) the assumption that albacore growth follows the Gompertz curve may be unwarranted; (b) the number of observations may be inadequate; (c) there is the possibility that there is differential growth between the sexes after the onset of sexual maturity, causing an unbalanced sex ratio in favor of males among the larger albacore (Otsu and Uchida, 1959*b*). If this is true, then the growth curves are subject to inaccuracies in the upper portions representing fish larger than 90 cm., the approximate size at which the albacore is believed to attain sexual maturity. A differential growth rate may have been responsible for the slightly

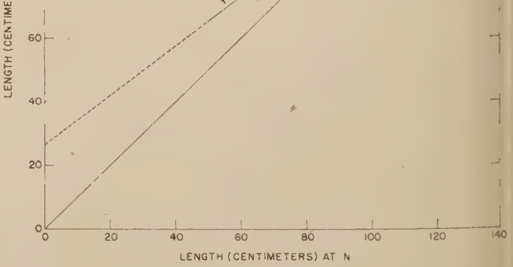

FIG. 5. Growth shown by tagged fish plotted by Walford's (1946) method and fitted with a straight line. The intersection of this line and the line $L_n = L_{n+1}$ indicates the upper asymptote of the albacore's length. Fish No. 2 was excluded from calculation of the regression line.

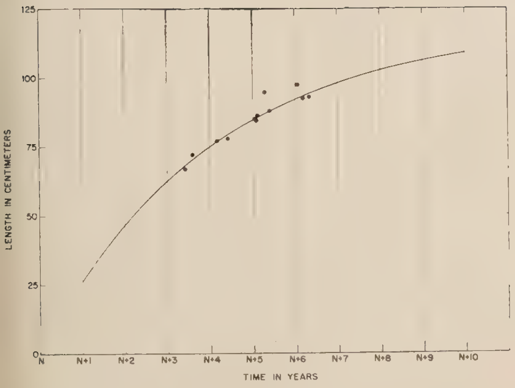

FIG. 6. Portion of growth curve of albacore obtained by Walford's method. Observed data are superimposed.

low estimate of the upper asymptote (Fig. 5) and for the deviation of the observed data from the upper portions of both curves (Figs. 6, 7).

Some studies have been made in the past on the age and growth of albacore, such as those by Uno (1936*a*; 1936*b*), Aikawa and Kato (1938), Partlo (1955), and Figueras (1955), all of which were based on the vertebral method of age estimation. Otsu and Uchida (1959*b*) also attempted to determine the age of albacore by this method and concluded in their study that the rings found on the centrum are probably not annuli as assumed by the several workers, but rather are growth marks laid down randomly with respect to time, and that, therefore, aging could not be accomplished by this method. In addition, they thought that the vertebral method generally yielded growth curves that were too linear to be typical and growth rates that were too slow when compared with the evidence from the then meager tag returns. The results of this study substantiate their criticisms.

TABLE 3

GROWTH RATES OF ALBACORE DERIVED BY FITTING TAG RECOVERY DATA TO GROWTH CURVES BY THE METHODS OF WALFORD AND RIFFENBURGH

AGE* (years)	LENGTH (cm.)	
	Walford	Riffenburgh
1	—	7.5
2	—	17.3
3	26.3	31.5
4	46.8	46.5
5	62.7	62.5
6	75.1	75.0
7	84.8	86.0
8	92.3	94.5
9	98.2	101.0
10	102.7	106.0

* The ages given are based on an arbitrarily selected origin (Fig. 7) and are therefore tentative.

The growth curves in question are compared with the curve obtained in this study (Fig. 8). Since the ages assigned in this paper (Fig. 7, Table 3) were arbitrarily defined, and since there are obvious discrepancies in the ages assigned by various workers, the mean lengths are plotted at yearly intervals without regard to the specific ages given. In other words, the curves in Figure 8 may be shifted freely in either direction along the abscissa. It is noted that the several growth rates do not differ markedly in magnitude.

It is clearly seen, however, that the presently derived curve, at least a portion of which is believed to be a fair representation of the actual albacore growth curve, is curvilinear, while the others, with the possible exception of Uno's (1936*b*) results, are almost perfectly linear. This difference in curvature supports the contention that the age of albacore could not be determined by the vertebral method. The linearity suggests that the rings found on the vertebrae are associated with growth rather than with age, and that ring formation is a linear function of fish growth.

Aside from growth studies by the vertebral

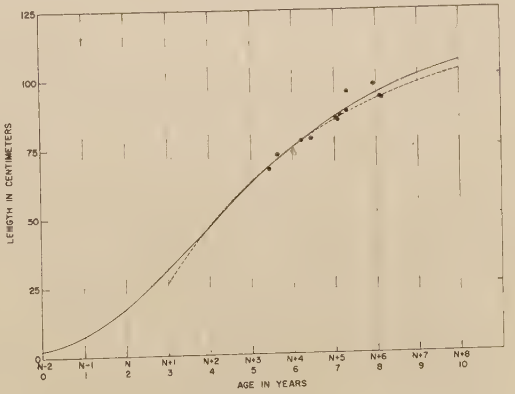

FIG. 7. Growth data fitted to a Gompertz equation by Riffenburgh's short method. The curve obtained by Walford's method (dashed) is superimposed. Observed data are superimposed on the Gompertz curve.

method, several workers have analyzed albacore size frequencies. Brock (1943) found two regularly occurring modal groups in the California length frequencies for the years 1924 to 1928 inclusive. The consistency in the appearance of these groups indicated that they were year classes. A more uniform relation was seen in the "lagged difference," or the difference in the modal size of group A in 1 year with that of group B in the following year, rather than between the two modal groups of the same year. The modal lengths (lagged) of both California and Oregon albacore are reproduced in Table 4.

The lagged modal values for the California albacore fall in nearly perfect agreement with the growth shown by the tagged fish, indicating that the distinctly bimodal distribution represents two age groups, one a year older than the other, as postulated by Brock. The growth of the Oregon albacore, on the other hand, was somewhat less than that estimated for the California albacore, and consequently lower than the growth shown by the tagged fish.

Suda (1954) has examined the size distribution of albacore taken in the Japanese winter long-line season and has traced six different size groups which appear yearly. The modes of these groups were: 57 cm., 67 cm., 78 cm., 89 cm., 100 cm., and 111 cm. The spacing of the intervals is uniformly 10 or 11 cm., thus representing a straight-line growth if these length groups are assumed to be age classes. The author concluded that these length groups may be considered as age groups if they are handled as five groups consisting of ages I to IV and an advanced age group which includes the last two modal groups. If these modal lengths are compared with the results obtained from tagging, it is seen that as in the case of the results obtained by the vertebral method, the yearly growth increments do not differ greatly, but there is a marked difference in the curvatures of the two curves. Suda pointed out that since growth of most living organisms is logistic, it may be unreasonable to postulate these length groups as age groups. However, he advanced the possibility that these age groups fall within the relatively straight portion of the growth curve. This is not indicated by the data presented in this paper.

TABLE 4

Modal Lengths of California and Oregon Albacore, in Centimeters

(Reproduced from Table 7, Brock, 1943)

GROUP A	GROUP B	DIFFERENCE
CALIFORNIA ALBACORE (1924 to 1928)		
1924, 64.89	1925, 77.18	12.29
1925, 64.87	1926, 77.16	13.29
1926, 68.84	1927, 81.04	12.20
1927, 65.80	1928, 78.27	12.47
OREGON ALBACORE (1938 to 1940)		
1938, 66.18*	1939, 74.19	8.01
1939, 64.02	1940, 74.26	10.24

* Only a single small sample was taken in 1938 after the season was underway.

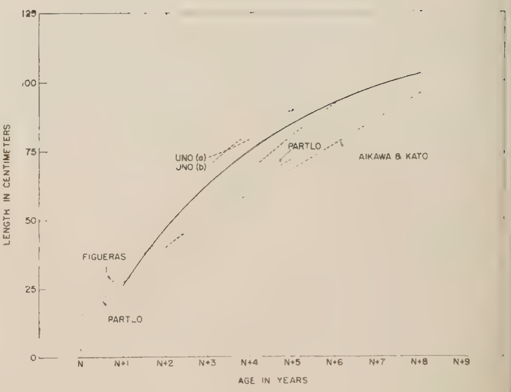

Fig. 8. A comparison of the growth curves obtained by the vertebral method with the Walford curve obtained in this study. Specific ages are disregarded in the plotting of these curves.

DISCUSSION

The tag recoveries have shown that albacore migrate considerable distances, and from one fishery to another, suggesting that there is a single population of albacore in the temperate North Pacific, exploited seasonally by Americans off the West Coast during the summer and fall, by the Japanese in mid-ocean during the winter, and also by the Japanese in the western Pacific during the spring and summer.

While no recoveries of albacore tagged off Japan have yet been reported in the American fishery, there are suggestions of movements in that direction. For example, recoveries 11 and 12 were of fish tagged within a week of each other in waters of the American fishery off the Pacific northwest. One was recaptured in June, 1958, in the Japanese live-bait fishery, and the other, a month later in the American fishery. The suggestion is that the latter had also undergone an extensive migration to the west before returning to the American fishery, although this movement may not have been as complete as the other. A similar suggestion is made by the recapture in the American fishery after 306 days of an albacore tagged by the California Department of Fish and Game. One other albacore, tagged at the same time, had been recaptured a month earlier 145 miles east of Tokyo, Japan (Anonymous, 1957). An appreciable tagging program by the Japanese may show definitely whether or not there is a movement of fish from the Japanese live-bait fishery into the American fishery.

However, judging by the sizes of fish generally taken in the different fisheries, it is possible that even extensive tagging by the Japanese would not confirm such a movement towards the east. The chances for American recovery of Japanese-tagged fish are not good unless the Japanese tag unusually small fish or unless unusually large fish move into the American fishery in large numbers. The sizes of fish commonly taken in the respective fisheries are shown in Figure 9. The American West Coast fishery generally takes smaller albacore than either the Japanese live-bait fishery or their long-line fishery; the fish range in size from about 50 to 85 cm. with the predominant sizes around 65 cm. The bulk of the fish taken by the Japanese is larger than 70 cm. in length, and these sizes comprise only a very small part of the American landings. On the other hand, small albacore under 70 cm. may be present in larger numbers in the Japanese live-bait fishery than indicated in Figure 9. Suda (1955) states that such small fish constitute a significant portion of the landings during certain years. The chances for recovery would seemingly be improved if tagging is concentrated on such small fish.

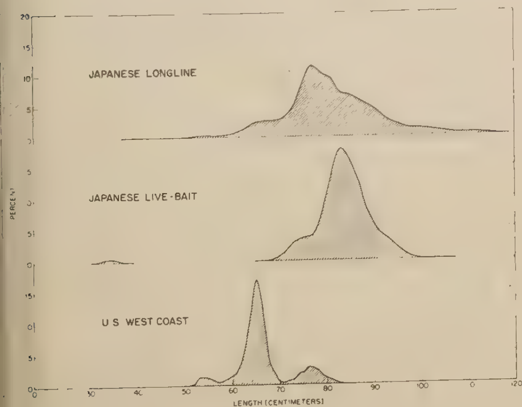

FIG. 9. Examples of albacore sizes taken by the major North Pacific fisheries. The Japanese size-frequencies were obtained from Nankai Regional Fisheries Research Laboratory (1951). The West Coast length frequency is based on unpublished data of the Oregon Fish Commission and are measurements made on albacore landed in Oregon during the 1957 season.

Although there appears to be little chance for fish tagged in the western Pacific to be recovered in the American fishery, a large-scale tagging program by the Japanese stands to serve an equally important purpose, that of elucidating the relationship between the albacore of the temperate and tropical Pacific Ocean. There is at present no direct knowledge concerning the movements of the larger albacore. The larger fish of the temperate North Pacific appear to move south into tropical and subtropical waters, perhaps to form the reproductive segment of the population. If there is such a southward migration of the larger fish, this may be shown someday by the recovery of a tagged fish. With Japanese vessels exploiting wide areas in the tropical Pacific, chances for recovery of fish tagged in the north should be favorable.

With respect to the growth curve obtained in this study, there are certain implications which merit brief consideration. If the Gompertz curve (Fig. 7) is a true representation of albacore growth, then the following points may be made: (a) the albacore is a relatively slow-growing tuna; (b) this species has a relatively long life span. Furthermore, as mentioned, it is believed that an albacore attains sexual maturity at a length of about 90 cm. If this is so, then it requires between 7 and 8 years for an albacore to become sexually mature. This is a significant portion of the life span. Since albacore enter the fisheries in substantial numbers at around 50 cm. in length (Fig. 9), a year-class is thus exploited for about 4 years before it even attains maturity.

SUMMARY

Of 1,201 albacore tagged in the temperate North Pacific Ocean by POFI between January, 1954, and August, 1957, 15 recoveries (1.2 per cent) were reported. These recoveries indicate considerable movement of fish in the North Pacific. Albacore tagged in mid-ocean north of Hawaii have been retaken in the American West Coast fishery as well as in the Japanese fisheries. Certain recoveries were of fish which migrated across the Pacific from the American West Coast to the vicinity of Japan. There is indication that Americans and the Japanese are exploiting the same population of albacore in the temperate North Pacific Ocean.

The data on growth, although insufficient for a conclusive study, were subjected to a preliminary analysis by Walford's method of growth curve transformation, and the resulting data were also fitted in a Gompertz equation. The derived growth curves are presented.

At least those portions of the growth curves for which there are observed data appear to be a reliable representation of albacore growth. These curves are curvilinear, contrary to several linear albacore growth curves reported in the past by workers who based their studies mainly on the vertebral method. The linearity of the latter curves suggests that the age of albacore cannot be determined by the vertebral method; the rings on the centra are probably directly associated with growth rather than with age.

The results indicate that the albacore is a relatively slow-growing tuna with a rather long life span. A significant portion of the life span is passed in the immature state.

Although POFI in cooperation with the Japanese has tagged 270 albacore in the Japanese live-bait fishery, and the Japanese have recently started a tagging program in the western Pacific, none of these fish has been recovered in the American fishery. In view of the fact that the Japanese exploit generally larger albacore than the Americans, the chances for recovery in the American fishery of Japanese-tagged albacore are far less than for Japanese recovery of American-tagged fish.

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ROBERT H. RIFFENBURGH

A NEW METHOD FOR ESTIMATING PARAMETERS FOR THE GOMPERTZ GROWTH CURVE

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A New Method for Estimating Parameters for the Gompertz Growth Curve

By

Robert H. Riffenburgh*)

Mathematical Statistician Honolulu Biological Laboratory, U. S. Bureau of Commercial Fisheries, Honolulu, Hawaii**)

1. Introduction

There are three major uses for biological growth curves:—

(a) to compare differences in growth phenomena and perhaps conduct tests of these differences;
(b) to describe the changes in growth phenomena under varying conditions of environment and/or heredity;
(c) to describe the ideal growth phenomenon (that which is expected to be typical);

(a) has been extensively investigated in papers by Wishart (1938) and Rao (1958); (b) usually involves a comparison of growth phenomena for each of the varying conditions and hence reduces to (a). When (b) is purely descriptive, it involves initiating the investigation from given conditions or assumptions and obtaining the curve in terms of these conditions. Item (c) starts with empirical data and attempts to obtain a curve that will exactly describe the growth phenomenon. This paper is concerned with (c).

A recent paper by Richards (1959) presents a general growth curve based on four parameters which admirably relates the different curves that have been studied in the past. Although this general curve is of interest when in the early stages of growth study, it does add an additional parameter to be estimated. The present paper is concerned with the subordinate problem of estimating the remaining three parameters given the fourth has been chosen such that the growth curve takes on the form of the Gompertz curve.

Growth curves are almost always asymmetric (Brody, 1945), so that while several workers have investigated symmetric curves, their work is usually inappropriate for purpose (c). The curve of von Bertalanffy (1938) has been given particular attention lately (e. g. Beverton and Holt, 1957), but it is an exponential curve everywhere concave downward so is also inappropriate for

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**) Also on the mathematics faculty, University of Hawaii, Honolulu, Hawaii.

purpose (c). The only asymmetric sigmoid curve cited in the literature is that of GOMPERTZ (1825). The Gompertz has classically provided good fits, its parameters are shown (WEYMOUTH and MCMILLIN, 1930) to relate to biological considerations, and it has rather extensive applications including as growth of individual animals and plants, growth of animal and microorganic populations, regeneration of tissue, mortality, chemical reactions (catalytic, temperature, etc.) (THOMPSON, 1948), engineering applications (DAVIS, 1955), and psychological learning curves.

Currently the use of the Gompertz suffers from lack of techniques to estimate its parameters. BRODY (1945) infers series expansion is necessary, stating that it is therefore of little practical use. It is the purpose of this paper to derive methods of estimating the Gompertz parameters.

For the Gompertz function

$$y = a\, b^{c^t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

it can be easily shown that, for maximum likelihood estimation, no unique solution exists for a and b and no finite solution exists for c. No other method of obtaining estimators of the general parameters in terms of the independent variable has been found by the author or has been found in the literature. For the special case in which a is unity, a "log log" transformation will yield a function of y linear with a function of t and the usual techniques of linear estimation may be employed to find estimators of b and c; such a special case is not usual.

There is another way to obtain estimators. The Gompertz function is single-valued and continuous in both the independent and dependent variables. Therefore, the dependent variable, y, may be employed exclusively in obtaining estimators of parameters. Solutions in the dependent variable have been obtained and are given here.

One solution was obtained by SCHULER and is given in DAVIS (1955) for problems associated with chemical engineering. A second solution, somewhat more general, was obtained by the author and is given in two aspects, viz., a long and a short method. SCHULER's method is given first. A derivation and a proof necessary to the author's method follow and then his long and short methods.

2. Schuler's Method

Suppose there are $3n$ values of t for equation (1) such that $t_{i+1} - t = t_{j+1} - t_j$, $i, j = 1, 2, \ldots, 3n$. Let (1) be reduced to the form

$$\log y_t = \log a + c^t \log b. \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Consider the quantities

$$S_1 = \sum_{t=1}^{n} \log y_t = n \log a + \left(\sum_{t=1}^{n} c^t \right) \log b \quad \ldots\ldots\ldots\ldots (3)$$

$$S_2 = \sum_{t=n+1}^{2n} \log y_t = n \log a + \left(\sum_{t=n+1}^{2n} c^t \right) \log b \quad \ldots\ldots\ldots\ldots (4)$$

$$S_3 = \sum_{t=2n+1}^{3n} \log y_t = n \log a + \left(\sum_{t=2n+1}^{3n} c^t \right) \log b \qquad (5)$$

It can be easily shown that

$$\frac{S_1 - S_2}{S_2 - S_3} = \frac{1}{c^n} \qquad (6)$$

and that

$$\log b = \frac{S_1 - S_2}{\sum_{t=1}^{n} c^t (1 - c^n)}$$

$$= \frac{(S_1 - S_2)(1 - c)}{(1 - c^n)^2} \qquad (7)$$

from which estimates of c and b can be found. If (2) is solved for log a and the appropriate functions of the estimates of b and c substituted, there is obtained the expression

$$\log a = \frac{1}{n} S_1 - \frac{S_1 - S_2}{1 - c^n} \qquad (8)$$

from which an estimate of a may be obtained.

It can be seen that SCHULER's technique exhibits certain disadvantages. The number of observations must be $3n$, n a positive integer, and the independent variable values must be integers obtained at equal intervals. $3n$ logarithms must be obtained. Aside from restrictions on the independent variable observations, it is seen that, while c is a function of all three sums, a and b are obtained as functions of the first two sums only. This is a waste of data and may introduce bias. Furthermore, using the sums representing the lower part of the curve (concave upward), the center part (relatively straight), and the upper part (concave downward) as if they were three random observations suggests the introduction of further bias.

3. A Basic Derivation

Consider any three pairs of observations, say y_i, y_{i+j}, and y_{i+k}, with the respective integral t-values, i, $i + j$, and $i + k$, $k > j > i > 0$. From (1),

$$\frac{y_{i+k}}{y_{i+j}} = \frac{a\, b^{c^{i+k}}}{a\, b^{c^{i+j}}} = b^{c^i (c^k - c^j)} \qquad (9)$$

Similarly,

$$\frac{y_{i+j}}{y_i} = b^{c^i (c^j - 1)} \qquad (10)$$

Then in general,

$$\frac{\log \dfrac{y_{i+k}}{y_{i+j}}}{\log \dfrac{y_{i+j}}{y_i}} = \frac{c^i (c^k - c^j) \log b}{c^i (c^j - 1) \log b} = (c^k - c^j)(c^j - 1)^{-1} \qquad (11)$$

Frequently k can be chosen such that $k = 2j$. In this case,

$$\frac{\log \dfrac{y_{i+k}}{y_{i+j}}}{\log \dfrac{y_{i+j}}{y_i}} = c^j \qquad \text{(12)}$$

Equations (11) or (12) may be solved for c, since the left-hand side of the equation is a numerical value. In general, $0 < c < 1$.

The estimate for c can be substituted for c in the following equations to obtain an estimate for b. In general,

$$\frac{\log^2 \dfrac{y_{i+k}}{y_{i+j}}}{\log \dfrac{y_{i+j}}{y_i}} = \frac{c^{2i}(c^k - c^j)^2 \log^2 b}{c^i (c^j - 1) \log b} = \frac{c^i (c^k - c^j)^2 \log b}{c^j - 1} \qquad \text{(13)}$$

or

$$\log b = \frac{(c^j - 1) \log^2 \dfrac{y_{i+k}}{y_{i+j}}}{c^i (c^k - c^j)^2 \log \dfrac{y_{i+j}}{y_i}} \qquad \text{(14)}$$

In the special case in which $k = 2j$,

$$\log b = \frac{\log^2 \dfrac{y_{i+k}}{y_{i+j}}}{c^{i+k}(c^j - 1) \log \dfrac{y_{i+j}}{y_i}} = \frac{\log \dfrac{y_{i+k}}{y_{i+j}}}{c^{i+j}(c^j - 1)} \qquad \text{(15)}$$

An estimate of b may be obtained from (14) or (15). In general, $0 < b < 1$.

The estimates for c and b may now be substituted for c and b in the following equations to obtain an estimate for a.

$$\log (y_i + y_{i+j} + y_{i+k}) = \log a + \log (b^{c^i} + b^{c^{i+j}} + b^{c^{i+k}}) \qquad \text{(16)}$$

or

$$\log a = \log (y_i + y_{i+j} + y_{i+k}) - \log (b^{c^i} + b^{c^{i+j}} + b^{c^{i+k}}) \qquad \text{(17)}$$

from which an estimate for a may be found.

Now we have estimates for a, b, and c from three and only three observations.

4. A Proof

We wish to prove that the first two moments of the Gompertz function exist. For convenience in series expansion, let us choose the Gompertz form used by WEYMOUTH and MCMILLIN (1930), viz.,

$$y = Ae^{-Be^{-Cx}} \qquad \text{(18)}$$

We lose no generality if we let $0 \leq x < t < \infty$.

$$\mu = \int_0^t xAe^{-Be^{-Cx}} dx$$

$$= A \int_0^t x \left(1 - Be^{-Cx} + \frac{B^2}{2!} e^{-2Cx} - \ldots \right) dx$$

$$= A \int_0^t \sum_{i=0}^{\infty} (-1)^i \frac{B^i}{i!} x\, e^{-iCx}\, dx$$

$$= A \sum_{i=0}^{\infty} (-1)^i \frac{B^i}{i!} \int_0^t x\, e^{-iCx}\, dx$$

$$= A \sum_{i=0}^{\infty} \frac{B^i (-1)^i}{i!\, i^2 C^2} \left[e^{-iCt} (-iCt - 1) + 1 \right] \ldots\ldots\ldots\ldots\ldots\ldots (19)$$

But the alternating infinite series (19) is less term by term than the series expansion of e^B, which is absolutely convergent. Therefore (19) is absolutely convergent and μ exists.

Similarly,

$$\mu_2' = \int_0^t x^2 A e^{-Be^{-Cx}} dx$$

$$= A \sum_{i=0}^{\infty} \frac{(-1)^i B^i}{i!} \left[\frac{t^2 e^{-iCt}}{-iC} + \frac{2}{iC} \int_0^t x\, e^{-iCx}\, dx \right]$$

$$= A \sum_{i=0}^{\infty} \frac{(-1)^i B^i}{i!} \left[\frac{t^2 e^{-iCt}}{-iC} + \frac{2}{i^3 C^3} \left\{ e^{-iCt} (-iCt - 1) + 1 \right\} \right]$$

$$= A \sum_{i=0}^{\infty} \frac{(-1)^{i+1} B^i}{i!\, iC} \left[e^{-iCt} \left\{ (t + iC)^2 + 2 - 2e^{iCt} - i^2 C^2 \right\} \right] \ldots (20)$$

Let a_i denote the ith term of (20). There exists a number N such that, whenever $i > N, |a_i| < \mu_i$, where μ_i is the ith term of the absolutely convergent series e^B. Thus (20) is an absolutely convergent series and μ_2' exists.

Thus the first two moments of the distribution (18) exist.

5. The Long Method

The author's method of fitting parameters to the Gompertz equation involves one restriction it shares with SCHULER's method: the abscissa values must be integers. However, the restriction of equal intervals is absent so that this restriction can be circumvented by a scale transformation. The sample size will be $3n \overset{0}{\pm} 1$, which may be read "$3n$, $3n$ increased by one, or $3n$ decreased by 1". The procedure in paragraph 3 above may be utilized n times. This may necessitate one observation, which may be chosen randomly, being used twice or being rejected from use. Utilization of the procedure n times will yield n estimates of a, b, and c.

If we average these n estimates for each parameter, we obtain a new set of estimates for a, b, and c, say a_0, b_0, and c_0. In paragraph 4, it was shown that the first two moments exist for the Gompertz function. a, b, and c are functions, always finite for finite $y \neq 0$, of the observed y's, rather than of the observed t's as in usual estimation procedure. Thus the first two moments also exist for the distributions of each a, b, and c, by SLUTSKY's theorem (CRAMER, 1946). The existence of these moments permits the use of the central limit theorem. Thus each of a_0, b_0, and c_0 are distributed normally with distribution mean equal to the respective parameters. We have, then, that our estimates, a_0, b_0, and c_0, approach the respective parameters stochastically as n increases. For large n this method is legitimate and should yield much more accurate estimates than does SCHULER's technique. It is, however, a lengthy procedure for large n.

If measures of accuracy of estimation are desired, confidence intervals on the estimates could be obtained by use of the central limit theorem.

6. The Short Method

If a rapid estimation is desired, any three pairs of the observations may be chosen and the procedure of paragraph 3 above followed to obtain estimates for a, b, and c. If the error deviation of the observations from the true relationship between the variables is not large, this estimation should be adequate for most cases.

How the three observations to be used will be chosen is arbitrary. It is suggested that the first datum be chosen randomly from the first third of the number of observations and the remaining two data be chosen from the second and third thirds respectively such that $k = 2j$.

7. The Estimation of Age and Growth of Yellowfin Tuna

A paper by MOORE (1951) is concerned with the estimation of age and growth of yellowfin tuna. He obtains size (modal length) at a certain stage in growth and arbitrarily designates this size as associated with age N. Then he obtains age for other sizes in terms of $N + 1$, $N - 2$, etc. He postulates that a Gompertz growth curve represents the modal growth of the population. He extrapolates the spawning period from the condition of the gonads and from this extrapolates the time of birth. The curve is apparently a freehand sketch.

Using the techniques of the present paper, it is possible to obtain estimates of the parameters of a Gompertz equation from the data points without age being known.

Let us analyse MOORE's data using the techniques of this paper. Let the time units t be months and let us arbitrarily designate the first data point as $t = 1$. Then the 25 data points are given as in Table 1.

Let us postulate that a Gompertz curve represents the relationship between the length in centimetres, y, and the age of the yellowfin tuna in months, t. Since we chose an arbitrary $t = 1$, the origin will have to be moved d units along the t-axis in order for the resultant curve to coincide with the data points. Thus, the postulated function is of the type

$$y = a\, b^{c^{(t+d)}} \qquad \text{(21)}$$

After obtaining estimates for the parameters in (21), we have the time of birth (or hatching) and may find the length at any age in months after birth.

Table 1

Modal values of lengths associated with arbitrary age designation for yellowfin tuna taken in Hawaiian waters

t (age in months)	y (length in cm)	t (age in months)	y (length in cm)
1	47·2	28	138·7
2	47·2	29	140·3
9	69·7	30	138·7
12	93·0	31	146·3
13	93·0	34	156·4
20	125·3	35	152·1
21	120·2	38	152·4
22	125·3	39	158·2
23	130·1	41	156·4
24	142·6	43	162·5
25	134·5	44	163·1
26	138·7	53	167·6
27	138·7		

Following the technique of this paper, we could use either the long or the short method. It was not shown how rapidly the estimates by the long method converge to the parameters. The author feels intuitively that eight triplets of observations is an inadequate number for convergence and therefore the short method which is considerably simpler numerically is appropriate.

All sets of triplets y_i, y_{i+j}, and y_{i+k} having the property $k = 2j$ were obtained and one was chosen randomly. This triplet contained the data points (13, 93·0), (27, 138·7), and (41, 156·4). From (12),

$$c^{14} = \frac{\log \dfrac{156\cdot4}{138\cdot7}}{\log \dfrac{138\cdot7}{93\cdot0}} = \frac{\log 1\cdot1276}{\log 1\cdot4914} = \frac{0\cdot05215}{0\cdot17359} = 0\cdot30042 \quad \ldots\ldots\ldots (22)$$

$$\log c = \frac{1}{14} \log 0\cdot30042 = \frac{1}{14} (-\, 0\cdot52227) = -\, 0\cdot03730 \quad \ldots\ldots\ldots (23)$$

$$c = 0\cdot91770 \quad \ldots\ldots\ldots (24)$$

From (15),

$$\log b = \frac{\log \dfrac{y_{41}}{y_{26}}}{c^{41} - c^{27}} = \frac{0\cdot05215}{0\cdot02956 - 0\cdot09838} = -\, 0\cdot75777 \quad \ldots\ldots\ldots (25)$$

$$b = 0\cdot17468 \quad \ldots\ldots\ldots (26)$$

From (17),

$$\begin{aligned} \log a &= \log (y_{13} + y_{27} + y_{41}) \\ &\quad - \log (\text{anlog } c^{13} \log b + \text{anlog } c^{27} \log b + \text{anlog } c^{41} \log b) \\ &= \log 388\cdot1 - \log (0\cdot56480 + 0\cdot84226 + 0\cdot94972) \\ &= 2\cdot58894 - 0\cdot37232 = 2\cdot21662 \quad \ldots\ldots\ldots (27) \end{aligned}$$

$$a = 164\cdot78 \quad \ldots\ldots\ldots (28)$$

Table 2

Some age and size relationships for yellowfin tuna obtained from equation (30)

t (months after birth)	y (cm length)	t (months after birth)	y (cm length)
0	0·2	35	117·1
5	1·8	40	132·0
10	8·9	45	142·6
15	24·6	50	150·0
20	50·5	60	158·3
25	73·6	70	162·0
30	97·5	80	163·6

It may be noted that

$$\lim_{t \to \infty} a\, b^{c^{(t+d)}} = \lim_{v \to 0} a\, b^{v} = a \quad \ldots\ldots\ldots\ldots\ldots\ldots (29)$$

so that 164·78 cm is the estimate of the asymptotic modal maximum of growth.

Inspection of the curve obtained from the estimates (24), (26), and (28) showed that if the origin were translated 16 units to the left, the curve would pass satisfactorily through the data points. This gives 16 as an estimate of d. (21) then becomes in this specific case,

$$y = (164{\cdot}78)\,(0{\cdot}17468)^{(0{\cdot}91770)^{(t+16)}} \quad \ldots\ldots\ldots\ldots\ldots (30)$$

Table 2 gives y for several values of $t' = t + 16$ (t' is the age after birth). It is seen that a 6 year-old yellowfin will have very nearly attained his maximum possible growth. Also, the size of the yellowfin at birth is given as 0·2 cm, which is quite reasonable.

Figure 1 shows the curve MOORE obtained for his data with the curve (30) superimposed. (30) gives birth about five months earlier than does MOORE. It is apparent from inspection that (30) yields as good a fit, despite having been obtained from only three data points.

Summary

The problem is to obtain an expression for the ideal growth curve of an organism (or other phenomenon) given a set of observations. Growth curves are discussed and the Gompertz curve posited. Methods for obtaining estimates of the Gompertz parameters are compared. Two new methods, both based on the same technique, are given. The long method provides estimates which converge in probability to the parameters as the sample size grows large, but involves a great deal of numerical calculation. The short method gives rapid and simple first approximations to the parameters, but is considerably less accurate.

A numerical example is given. Length data on yellowfin tuna from Hawaiian waters are analysed and an estimate of the growth curve is obtained; an estimate of the time of birth is also obtained so that length can be found as a function of age.

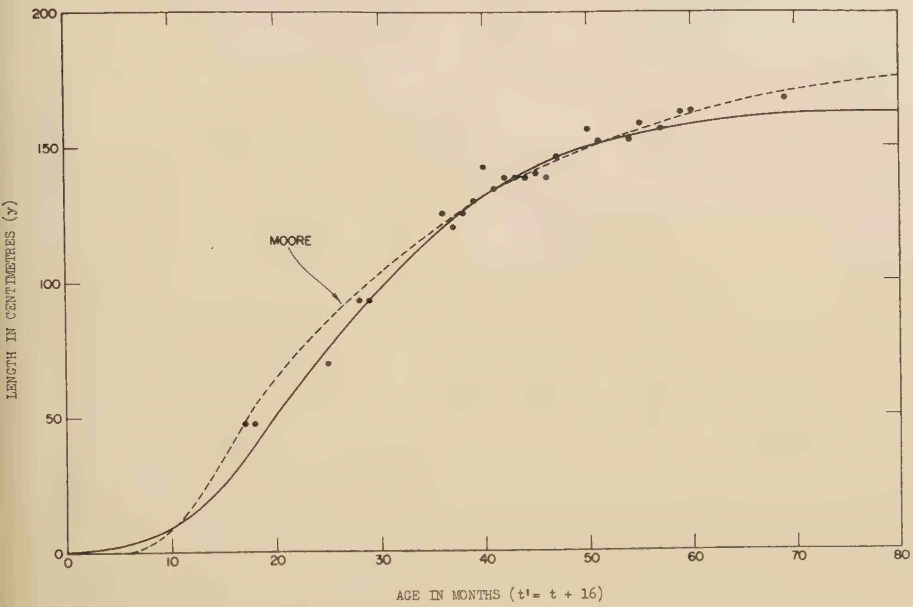

Figure 1. Growth curves of yellowfin tuna after Moore (1951) and by the method of this paper with actual modal values in length superimposed.

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A SYSTEM ANALYSIS OF THE MARINE ECOLOGY

by

ROBERT H. RIFFENBURGH*
Mathematical Statistician
Bureau of Commercial Fisheries
Honolulu Biological Laboratory
Honolulu, Hawaii

Introduction

An ecological problem in fisheries research is that of describing explicitly the complicated interrelationships among population size, recruitment, natural mortality, fishing mortality, and predation habits, among several species at each of several trophic levels. Although several individuals have studied population dynamics (cf. 1, 2, 4, 5), the usual approach has been to consider a single species exclusive of its interaction with other species. In this paper, an attempt is made to study the entire system.

In order to speak in general, let us consider r trophic levels with s_i species in the i-th trophic level. Thus, a variable x_{ij} refers to the measure of the variable x associated with the j-th species in the i-th trophic level; $j=1, 2, \cdots, s_i$; $i=1, 2, \cdots, r$. It is recognized that this classification system is somewhat arbitrary. In general the successive trophic levels are occupied by plants, herbivors, and carnivors, with whatever sub-classifications are necessary for the study of species of particular interest. The number of trophic levels and sub-levels in such a classification might be in the neighborhood of six. The species whithin each trophic level may be classified according to similarity of eating habits, i. e. those which feed on essentially the same prey would be classified together. The number of species within each trophic level in such a classification might be in the neighborhood of three or four.

In addition to this general problem of describing an entire system, there is a second problem of predicting the effects of external phenomena upon the equilibrium of the system, and perhaps predicting future balances that occur after an external phenomenon has effected an imbalance. By external phenomena I refer to such things as fishing mortality, which constitutes a loss from the system, or epidemics which produce large effects but occur so infrequently as to not constitute a regular part of the system. I hope here to contribute to the solution of both problems.

The fundamental part of the analysis depends upon measuring the mass and/or energy flux from each classification to each other classification The parameters involved must be estimated by a set of simultaneous equations derived from known biological relationships. Two cases will be treated:

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* Also on mathematics faculty, University of Hawaii, Honolulu.

Case I: the system is in equilibrium
Case II: the system is not in equilibrium.

For the first case, recruitment equals mortality in all classifications, so that only the mortality need be considered; the size (in weight) of the populations are constant. For the second case, recruitment does not equal mortality in all classifications and the sizes of the populations must be considered. Various amounts of matter will be postulated as being removed from the system by fishing or other causes and the pattern of probable results will be predicted by the use of Markov chains.

A cross classification of analysis is the consideration of the system based upon the variables:

Case A: the weight of animals (or plants)
Case B: a measure of transmitted energy.

Both have some disadvantages and each provides information not obtainable from the other.

Solutions: Case A-I

The basis on which the complete analysis is constructed assumes the knowledge of parameters π_{ijkl}=the probability that the weight of a random member of the j-th species of the i-th trophic level will be consumed in the given time interval (say a year) by a random member of the l-th species of the k-th trophic level; $i, k=1, 2,\dots r$; $j=1, 2, \cdots, s_i$; $l=1, 2,\dots, s_k$. To standardize such animal weights, a basic unit of "one pound" will be used. At the present time, such parameters are unkown and unestimated; they are unlikely ever to be known exactly. Methods of estimating such parameters are considered in the last section. For the present let us assume that p_{ijkl}, estimates of π_{ijkl}, are available.

For case A-I, the system is in equilibrium so that the weight of animals present in any one year is the same as the weight in any ensuing year.

Let us define a square matrix P, with dimensions $\sum_{i=1}^{r} s_i+1$, whose typical ik-th partition is P_{ik}, a sub-matrix with dimensions $s_i \times s_k$, whose typical element is p_{ijkl}. After the $\sum_{i=1}^{r} s_i$ rows and columns, there is an additional row and column. This last row is the vector

$$[0 \;\; 0 \;\; 0 \cdots 0 \;\; 1]$$

and the last column is composed of elements p_{ijf}, the probability that a pound of the j-th species of the i-th trophic level exits from the system, not to return. "Exit" will here mean that the pound is removed by fishing, but it could as well imply death by disease, radiation, or any other cause except predation. In order to have P a probability matrix, we must have the restriction:

$$\sum_{k=1}^{r} \sum_{l=1}^{s_k} p_{ijkl}+p_{ijf}=1. \tag{1}$$

Such a restriction is both reasonable and essential from a biological view. The probability p_{ijij} is the probability that the pound stays in its own species (either by remaining untouched or by cannibalism), p_{ijf} is the probability that the pound exits from the system, and all other p's are probabilities that the pound passes from one position in the system to another; thus all possibilities are accounted for and the sum of probabilities over the entire possibility space must equal unity.

P appears as follows:

$$\begin{bmatrix} p_{1111} & p_{1112} & \cdots & p_{111s_1} & p_{1121} & \cdots & p_{11rs_r} & p_{11f} \\ p_{1211} & p_{1212} & \cdots & p_{121s_1} & p_{1221} & \cdots & p_{12rs_r} & p_{12f} \\ \vdots & \vdots & & \vdots & \vdots & & \vdots & \vdots \\ p_{1s_111} & p_{1s_112} & \cdots & p_{1s_11s_1} & p_{1s_121} & \cdots & p_{1s_1rs_r} & p_{1s_1f} \\ p_{2111} & p_{2112} & \cdots & p_{211s_1} & p_{2121} & \cdots & p_{21rs_r} & p_{21f} \\ \vdots & \vdots & & \vdots & \vdots & & \vdots & \vdots \\ p_{rs_r11} & p_{rs_r12} & \cdots & p_{rs_r1s_1} & p_{rs_r21} & \cdots & p_{rs_rrs_r} & p_{rs_rf} \\ 0 & 0 & \cdots & 0 & 0 & \cdots & 0 & 1 \end{bmatrix} \tag{2}$$

Let us define by N the $1\times\left(\sum_{i=1}^{r} s_i+1\right)$ vector of n_{ij}, the number of pounds of the j-th species of the i-th trophic level entering the system for disposition during this time period. Of course the last element is zero, since no life which has left the system may reenter.

There are two types of quantities which are of particular interest: the size of the j-th species at the end of the time period and the total catch (or total pounds lost from the system). The vector NP would give these quantities if the animals were physiologically 100% efficient, i. e. if a pound eaten provided a pound of growth. Since the organisms are not 100% efficient, there results another source of loss of weight from the system in the form of waste products, etc. To account for this loss from the system, the probabilities in P should be weighted. This can be most easily effected by redefining the p_{ijkl} as the probability that a pound from species j of trophic level i will be consumed and fully utilized in growth by a member of species l of trophic level k. To conform to the restriction that the sum of elements of any row be unity, another row and column must be added to P, such that the bottom row vector is

$$[0 \quad 0 \cdots 0 \quad 0 \cdots 0 \quad 0 \quad 1]$$

and the last column vector is the transpose of

$$[p_{11x} \quad p_{12x} \quad \cdots \quad p_{1s_1x} \quad p_{21x} \quad \cdots \quad p_{rs_rx} \quad 0 \quad 1],$$

where

$$p_{ijx}=1-\sum_{k=1}^{r}\sum_{l=1}^{s_k} p_{ijkl}-p_{ijf}.$$

This p_{ijx} represents a second loss to the system, but one which is not utilized by man. The vector N adds one element, a zero, to have dimensions

$1\times\left(\sum_{l=1}^{r} s_r+2\right)$, and appears as :

$$N=[n_{11}\quad n_{12}\quad \cdots\quad n_{1s_1}\quad n_{21}\quad \cdots\quad n_{rs_r}\quad 0\quad 0]. \tag{3}$$

For case A-I in which equilibrium is assumed, the vector N is the set of weights entering the system each time period regardless of losses. Since the weight of a species remaining from the last time period plus this time period's recruitment equals the weight of the species entering this time period, $NP+R=N$ for case A-I, where R is a vector of recruitment quantities.

It should be observed that for case A, P is a patterned matrix in which the greatest number of partitions are null. If P be partitioned into a matrix in which the ik-th partition P_{ik} is the sub-matrix composed of the probabilities that the weight of the i-th trophic level goes to the k-th trophic level, then, assuming the weight of any trophic level is passed on only to the next higher level, P would appear as

$$\begin{bmatrix} \delta_{jl}p_{ij1l} & P_{12} & O & \cdots & O & P_{1f} & P_{1x} \\ O & \delta_{jl}p_{2j2l} & P_{23} & \cdots & O & P_{2f} & P_{2x} \\ O & O & \delta_{jl}p_{3j3l} & \cdots & O & P_{3f} & P_{3x} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ O & O & O & \cdots & \delta_{jl}p_{s_rjs_rl} & P_{s_rf} & P_{s_rx} \\ O & O & O & \cdots & O & 1 & 0 \\ O & O & O & \cdots & O & 0 & 1 \end{bmatrix} \tag{4}$$

where δ_{jl} is Kronecker's delta. It is obvious that any power of P will be triangular.

One possible application of the analysis thus far presented is the concept of increasing the commercial catch of a particular species or a set of species by exerting fishing pressures in some optimum pattern. Since fishing effort is independent of predation effort (i. e. in the sense that predation effort is fixed in advance of fishing effort, at least for small intervals of time, and the fishing effort is arbitrary to man), and by the restriction of rows summing to unity, a change (increment or decrement) of d_{ij} in p_{ijf} evokes a change in p_{ijkl} of

$$d_{ijkl}=-\frac{d_{ij}\,p_{ijkl}}{\sum_k\sum_l p_{ijkl}+p_{ijx}},\qquad d_{ijx}=-\frac{d_{ij}\,p_{ijx}}{\sum_k\sum_l p_{ijkl}+p_{ijx}} \tag{5}$$

Then the typical ij-th row of P becomes the vector

$$[(p_{ij11}+d_{ij11})\cdots(p_{ijrs_r}+d_{ijrs_r})(p_{ijf}+d_{ij})(p_{ijx}+d_{ijx})]. \tag{6}$$

The problem now is to choose the d_{ij} such that either the element of NP associated with the total catch per time period or the element $n_{ij}(p_{ijf}+d_{ij})$ for some ij is maximized. The solution for the latter in this case of equilibrium is trivial and ridiculous: increase d_{ij} until $p_{ijf}+d_{ij}=1$, in which case all fish of that species in the ocean are caught, but by the equilibrium restriction the number entering the next time period will be unaffected by the catch, which obviously does not conform to reality. It is apparent that this problem can be more profitably considered in case A-II.

Solutions: Case A-II

The situation in this case is much the same mathematically as in the preceding section, but with alterations as follows. With the restriction of equilibrium dropped, the vector R of recruitment quantities is not specified by N and P, and so must be considered independently.

Recruitment is variously thought by biologists to be related to population size and to be unrelated to population size. Since one female may produce very large number of eggs, the pertinent influences on number of larvae surviving to adulthood seem to be food availability and intensity of predation upon such larvae rather than the initial number hatched. I shall take this view, at least when extremely large population changes are not present, so that R is a vector of random variables independent of N (for large N). R may be written as $R=E(R)+\underset{\sim}{e}$, where $\underset{\sim}{e}$ is a vector of random deviations with zero expectation. Since we are considering essentially a "typical" system interrelationship rather than possible extremes of relationship, we shall take the vector of recruitment each time period to be $E(R)=\dot{R}$.

Taking N as in (3), P as in (4), we have the weight in the various populations at the end of the time period as:

$$N^{(1)}=NP+\dot{R}. \tag{7}$$

In case II, the weight of animals (or plants) entering any given time period is not restricted to be the same as for any other time period, so that it becomes of interest to follow the weight vector through successive time periods. Let us denote by $N^{(n)}$ the weight vector of populations at the end of the n-th time period (i. e. entering the $(n+1)$-th time period). By the usual theory of Markov chains we find

$$N^{(n)}=NP^n+\dot{R}\sum_{h=1}^{n}P^{h-1}, \tag{8}$$

where $P^0\equiv I$.

To pursue our example of choosing fishing efforts such as to maximize the sum of catches over many years, let us again cause a vector Δ of changes d_{ij} as defined in (5) to be effected on the vector of catch probabilities (by changing fishing effort) so that the typical row of P will appear as in (6). The desired solution is obtained by finding Δ to maximize one (or a set of) catch weight(s) summed over a desired number of time periods, i. e. maximize $\sum_{h=1}^{n} n_{ij}^{(h)}\, p_{ijf}+d_{ij}$, where $n_{ij}^{(h)}$ is the ij-th element of $N^{(h)}$ and the ij-th species is the species of commercial interest. Here n is a finite integer>0.

Let us now consider the ultimate result of the ecological system as defined. As n becomes large, $N^{(n)}$ approaches an ultimate disposition of weights.

$$N^*=\lim_{n\to\infty} N^{(n)}=N\lim_{n\to\infty} P^n+\dot{R}\lim_{n\to\infty}\sum_{h=1}^{n}P^{h-1}. \tag{9}$$

Since P possesses two absorbing states, $\lim_{n\to\infty} P^n$ will go to the form

$$\left[\begin{array}{c|c} O & A \\ \hline O & I \end{array}\right],$$

where A is a $\left(\sum_{i=1}^{r} s_i \times 2\right)$ matrix, the elements of whose rows sum to unity.

However, $\lim_{n\to\infty} \sum_{h=1}^{n} P^{h-1}$ contains P and $\dot{R}P$ has no null elements, which implies that N^* contains no null elements. This implies biologically that so long as an assumption of R with all non-null elements holds, the system will not disintegrate and no species will become extinct.

Implicit in the Markov chain is the assumption of fixed P. This assumption is reasonable for a steady state system which has been observed in isolated cases, but it is obvious that a marked change in relative density of two competing predators will alter the proportion of a prey species being consumed by each, and hence alter elements of P. Thus a more general analysis and prediction will be obtained if we define P_h as a P derived anew at the end of the h-th time period by the methods in the last section, whence (8) alters to

$$N^{(n)} = NP\prod_{h=1}^{n-1} P_h + \dot{R}\Big(\sum_{f=1}^{n-1}\prod_{h=f}^{n-1} P_h + I\Big). \tag{10}$$

Once a change is effected, and for $N^{(n)}$ as defined in (10), if there exists a positive integer ν such that $|N^{(n+1)} - N^{(n)}| \leq \varepsilon$ for every $n > \nu$, ε an arbitrarily small non-negative quantity, then the system is said to be able to return to equilibrium, and $N^{(n)}$ and P_n define to any desired degree of approximation the new equilibrium.

Solutions: Cases B-I, B-II

In case B, the unit transmitted from one species to another is not the weight of animals, but a more basic measure of energy (and/or matter). In this case, all organic matter may be considered. The diseased fish feeds his parasites and thus is not lost from the system. A fish eats, and produces waste products, which are acted upon by bacteria and are subsequently available as plant nutrients. In a complete analysis of this type, the path of *all* energy transfer is traced so that (except for removal by man) no energy is lost from the system. Heat loss is replaced by sunlight. River discharges are added to the system. Thus, a much more complete analysis is permissible, although the estimation of the probabilities involved will be much more difficult and likely less exact, which will limit the usefulness of this case. In a recent paper, Odum(3) discusses some of the variables involved in case B-I, but no attempt at a numerical analysis of the system or a predictive model was made, nor were feedbacks to one part from changes elsewhere in the system included.

Mathematically, P is defined as in (2), since the p_{ijx} are no longer necessary. Furthermore, any species may make a contribution of one sort or another to any other species, so that powers of P are not necessarily triangular.

Derivation of the matrix P

Estimators for the elements of P will be derived for case A. Estimators for case B are similar mathematically, but depend on more complex physiological measurement, which is not currently feasible.

Assumption 1. Foraging effort e_{ij} of species ij (or, more generally, the volume of water exposed to the predator) is a function of the density of predator ij.

Assumption 1 a. e_{ij} is approximately linear with n_{ij} with boundary condition (0, 0) and slope m_{1ij}, i.e. $e_{ij} \doteq m_{1ij} n_{ij}$.

Assumption 1 will be considered to be self-obvious; Assumption 1a should be justified. Consider separately predation by non-schooled and schooled animals. If the animals are randomly placed and non-schooled, and the measure of density is the continuous variate weight, then the volume of water exposed to a fixed number n_{ij} of species ij as the animals grow in weight will be constant or increasing linearly with a very small slope as the animals are non-self-mobile or self-mobile respectively. When an additional member of the species is recruited, the function e_{ij} takes a sudden increase or step. A line constructed through the steps represents the average function e_{ij} on n_{ij}, which illustrates that the scouting effort is approximately linear with the weight of individuals. The deviations from this line are very small. The slope m_{1ij} will be determined by the scale on the e_{ij}-axis. If the animals are schooled, the situation is precisely the same, except that the step represents the addition of a school rather than a single individual. The magnitude of the increment or step will be greater in each instance, but is still quite small relative to the weight of animals in the ocean.

Assumption 2. The weight of prey $i-1$, l consumed by ij, $n_{(i-1)le_{ij}}$, increases linearly with scouting effort, e_{ij}, with boundary condition (0, 0) for fixed prey density.

Then since a linear function of a linear function is linear,

$$n_{(i-1)le_{ij}} = m_{2ij} n_{ij}, \tag{11}$$

for fixed density of prey species $i-1$, l.

By analogous reasoning, if the prey density $n_{(i-1)l}$ of species $i-1$, l of predation interest to species ij is allowed to vary and n_{ij} is held fixed, we may arrive at

Assumption 3. The weight of prey $i-1$, l consumed by ij, $n_{(i-1)le_{ij}}$, increases linearly with an increase in density of $i-1$, l, $n_{(i-1)l}$, with boundary condition (0, 0) for fixed density of predator and fixed scouting effort.

Then

$$n_{(i-1)le_{ij}} = m_{3(i-1)l} n_{(i-1)l}, \tag{12}$$

for fixed n_{ij}.

Now if both n_{ij} and $n_{(i-1)l}$ are allowed to vary,

$$n_{(i-1)le_{ij}} = f(n_{ij}, \ n_{(i-1)l}),$$

where $f_1(n_{ij} \mid n_{(i-1)l}) = m_{2ij}\, n_{ij}$ and $f_2(n_{(i-1)l} \mid n_{ij}) = m_{3(i-1)l} n_{(i-1)l}$.

Then since

$$f(n_{ij}, \ n_{(i-1)l}) = f_3(n_{ij}) f_2(n_{(i-1)l} \mid n_{ij}) = f_4(n_{(i-1)l}) f_1(n_{ij} \mid n_{(i-1)l}),$$

we substitute to obtain

$$m_{3(i-1)l} n_{(i-1)l} f_3(n_{ij}) = m_{2ij} n_{ij} f_4(n_{(i-1)l}),$$

from which

$$f_3(n_{ij}) \propto n_{ij} \quad \text{and} \quad f_4(n_{(i-1)l}) \propto n_{(i-1)l}.$$

Then

$$n_{(i-1)leij}=f(n_{ij},\ n_{(i-1)l})\propto n_{ij}n_{(i-1)l}=b_{(i-1)lij}n_{ij}n_{(i-1)l} \tag{13}$$

where $b_{(i-1)lij}$ is an arbitrary scale parameter.

Denote by μ_{ij} an estimate of the mortality rate per time period of species ij (excluding cannibalism). Suppose these quantities are available (estimation techniques are largely biological and will not be discussed here). Denote by y_{ij} an estimate of the average diet in weight of species ij. These diets are estimable from growth curves of species plus knowledge of their physiological efficiencies. Also the p_{ijx} can be found physiologically, which will permit estimation of p_{ijkl} when n_{ij} and n_{ijekl} are found. Denote by v_{ijkl} an estimate of the proportion of diet of kl represented by ij. These diet quantities are estimable by stomach content analysis of kl or similar biological techniques. Denote by c_{ij} the catch or its estimate of ij per time period, which is a matter of record. Then the following equations emerge:

$$\mu_{(i-j)l}n_{(i-1)l}-\sum_{j=1}^{si}n_{(i-1)leij}-c_{(i-1)l}=0 \tag{14}$$

$$(1-\mu_{(i-1)l})=p_{(i-1)l(i-1)l} \tag{15}$$

$$n_{ij}v_{(i-1)lij}y_{ij}=n_{(i-1)leij} \tag{16}$$

$$\sum_{i=1}^{r}\sum_{j=1}^{si}n_{(i-1)leij}+(1-y_{(i-1)l})\,n_{(i-1)l}=n_{(i-1)l} \tag{17}$$

$$b_{(i-1)lij}=n_{(i-1)l}^{-1}n_{ij}^{-1}n_{(i-1)leij} \tag{18}$$

$$p_{(i-1)lij}=n_{(i-1)l}^{-1}n_{(i-1)leij}(1-p_{ijx}) \tag{19}$$

$$p_{(i-1)lf}=n_{(i-1)l}^{-1}c_{(i-1)l}. \tag{20}$$

Solving this set of equations, we now have the matrix P in addition to estimates of the total weight of animals of the various species.

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ABSTRACTS

An ecological problem in fisheries research is that of describing explicitly the complicated interelationships among population size, recruitment, mortality, predation habits, and fishing effort among the several species at each of several trophic levels. A second problem is that of predicting the effects of varied fishing efforts, epidemics and other external phenomena upon the equilibrium of the system, and perhaps predicting future balances that occur after an external phenomenon has effected an

imbalance. This paper is a first effort at providing a solution to both problems.

The fundamental part of the analysis depends upon measuring the amount of each classification contributed to each other classification as nutrient, and is in some ways similar mathematically to Leontief's economic input-output analysis. The parameters to be utilized must be estimated by a set of simultaneous equations derived from known biological relationships. Two cases are treated : the system is in equilibrium ; system is not in equilibrium. For the first case recruitment equals mortality in all classifications, so that only the mortality is analyzed : the size of the population is static. For the second case, the entire population must be considered, and additional classifications, e.g. the animals left alive, the amount of recruitment, etc., are added. The additional classifications cause mathematical problems, which are discussed.

A cross-classification of analysis is the consideration of the system based upon a variable : the weight of animals or plants ; and based upon a variable : a measure of transmitted energy. Both have some disadvantages and each provides information not obtainable from the other. Both are presented and discussed.

In order to consider the second problem, i.e. prediction of change in the system, various amounts of animals are postulated as being removed from the system due to fishing effort or other causes, and the pattern of probable results is predicted by the use of a modified Markov chain, along with expected results. The essential problem mathematically is that the stochastic matrix must be redefined after each time period in order to admit a feedback effect.

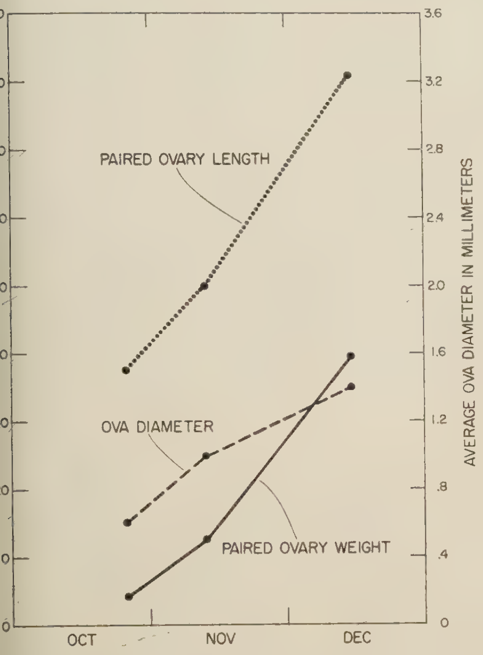

Fig. 1. Averages of ova diameter and paired ovary weight nd length of tomcod, *Microgadus tomcod*, collected from Octo- er to December 1959.

er. Examination was made for the presence of arasites, ruptured blood vessels, and general onad form before preservation in 10 percent ormalin solution.

The gonads were stored for a period of two veeks, after which time five pairs of ovaries from ach of the three samples were chosen at random or further examination. From each pair, the umber of ova in one gram was determined. The otal number of ova present in each pair of varies was then estimated by multiplying the umber of ova in one gram by the total weight f the pair. The average total number for each f the three samples, and the average of these verages, are given in Table 1. The mature tom- od produces an average of 20,000 ova, with a minimum of 6,000 and a maximum of 30,000. The ova showed an average increase in diameter from 0.6 mm. in October to 1.4 mm. in December (Fig. 1). Fig. 1 also shows the increase in ovary weight and length from the early developmental stages in October to December, when the peak of spawning activity is reached. The average weight of the mature paired ovary was 26 grams and the average length was 66 mm. (Table 1).

Bigelow and Schroeder (1953, *Fish. Bull. U. S. Fish and Wild. Serv. 53(74):577*) state that the spawning season of the tomcod begins in November and extends into February, with the peak beginning in late December. Our data are in agreement with their findings. A number of fertilized ova collected from Hull Harbor, December 19, had a conspicuous oil globule and distinguishable eye bulge. The ovaries of fish sampled increased in both length and weight from October to December. This increase seems to result from an increase in individual ova diamter (Fig. 1) and numbers of developing ova (Table 1).

Examination of mature eggs taken from a group of ovaries of the December 12th sample, showed an ova diameter of 1.4 mm. to 1.5 mm. This value agrees with the 1.5 diameter of newly spawned ova reported by Bigelow and Schroeder (*ibid*).

No significant observations were made on the presence of parasites and ruptured blood vessels; only gonad form was found to differ during the three months of sampling. The increase in gonad size seemed to constrict the alimentary canal and other internal organs; however, no critical analysis of this condition was made.—EVERETT SCHANER, *Oceanographic Laboratory, Randolph High School, Randolph, Massachusetts,* KENNETH SHERMAN,[1] *United States Fish and Wildlife Service, Bureau of Commercial Fisheries, Honolulu, Hawaii.*

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[1] Formerly on the staff as biology instructor at Randolph High School, Randolph, Massachusetts. Published by permission of the Director, U. S. Bureau of Commercial Fisheries.

DISPLAY C

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OBSERVATIONS ON THE FECUNDITY OF THE TOMCOD, *MICROGADUS TOMCOD* (Walbaum).—The tomcod, a relatively common inshore fish, is much sought after by Massachusetts fishermen, especially during the winter months. Little is known, however, of the fecundity of this fish and such data are presented here.

A total of 100 tomcod used in this study were collected, using hooks baited with the sea worm *Nereis virens* Sars, along the coast of Hull, Massachusetts, during three sampling trips in October, November, and December 1959. The sex ratio was approximately one male to every three females (27♂ to 73♀) in the total sample. In the laboratory the gonads from females were removed, weighed to the nearest tenth of a gram and measured in length to the nearest millime

TABLE 1. AVERAGE NUMBER OF OVA PRODUCED BY TOMCOD, *Microgadus tomcod*

Date	Sample number[1]	Paired ovary number	Weight of paired ovary (grams)	Average weight	Number of ova equal to one gram	Total number of ova	Average number of ova	Length of ovary mass (mm.)	Average length	Length of fish (mm.)	Average length
10/25/59	1	1	3.3		3,506	11,570		35		205	
		2	6.3		2,700	17,010		50		340	
		3	6.2		2,750	17,050		47		180	
		4	2.2		2,579	5,674		23		170	
		5	2.4		5,841	14,018		33		202	
			20.4	4.08	Total	65,322	13,064	188	37.6	1,097	219
11/14/59	2	1	18.7		1,026	19,186		55		215	
		2	14.1		1,392	19,627		55		255	
		3	6.6		2,112	13,939		40		205	
		4	12.6		1,717	21,634		50		220	
		5	10.4		1,734	18,034		50		190	
			62.4	12.48	Total	92,420	18,484	250	50.0	1,085	217
12/12/59	3	1	10.4		488	5,075		100		208	
		2	44.2		560	24,752		70		210	
		3	48.7		610	29,707		75		221	
		4	33.0		590	19,470		75		225	
		5	56.5		560	31,640		85		220	
			192.8	38.56	Total	110,644	22,129	405	81.0	1,084	217
	1 + 2 + 3			18.37			17,892		56.2		
	2 + 3			25.52			20,307		65.5		

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[1] Samples two and three were taken during the periods closest to spawning and represent the closest approximation actual spawning characteristics.

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ter the Hawaiian fishery are a portion of a popula-
n migrating from east to west in a body of low-
inity water suggestive of downstream California
rrent water. If this low-salinity water impinges on
e island area, skipjack in large numbers appear
the island fishery. The season is terminated either
the passage of the last wave of migrant fish, or
nply by retreat of the low-salinity water, or both.
ne migration of skipjack entering the island area
ay be disrupted and delayed in response to special
eding situations that they encounter. This hypoth-
is relegates the islands to the role of an operating
se for the fleet, rather than a base for the skipjack,
d is in accord with our failure to find significant seasonal differences in the standing crop of biota in the Hawaiian Islands and our observation that during a typical season skipjack are abundant far south of the islands, well beyond the possible influence of the islands, whereas indications are that they are not abundant very far to the north of Hawaii. The problem of change in size of the skipjack with the onset of a typical season is also susceptible to explanation for many populations of tuna to arrange themselves geographically by size, the most typical picture being the small fish in a population tending to dominate the extremities of the environment. If we interject this additional factor, we can understand the absence of large fish during the 1957 ‘‘season.’’

ADVECTION—A CLIMATIC CHARACTER IN THE MID-PACIFIC

GUNTER R. SECKEL
Pacific Oceanic Fishery Investigations

In an attempt to discover oceanographic changes in the Hawaiian Islands region which may be associated with the seasonal nature of the skipjack fishery and its annual fluctuations, we have been looking into what might be described as the "oceanographic climate" of the region. This involves a study of the time and space distribution of surface variables which by means of budget considerations will yield some information regarding the processes associated with these distributions. The following notes describe partial results of this study and may be of interest during the second portion of this Symposium.

Since the temperature is of primary interest in any climatic study, the following will deal with the heat budget of the surface layer. On the basis of conservation of heat one can say that at any locality in the ocean the net heat exchange across the sea surface must be balanced by the change in heat content of the water column, heat diffused through the sides of the column, and the heat carried in or out of the column by means of currents. Such an expression can become rather complicated. However, since this is to be a climatic study, interest lies with the gross seasonal changes and therefore some simplifying assumptions can be made for the Hawaiian survey region (10°-30°N., 150°W-180°).

In this area the mixed surface layer is generally well defined and since it has neutral stability one can say that heat exchanged across the sea surface is uniformly distributed throughout this layer. Furthermore, because of high stability in the thermocline just below the mixed layer, and small horizontal temperature gradients, vertical and lateral diffusion are assumed negligibly small compared to advection and heat exchange across the sea surface. With these assumptions the heat budget and the volume budget of a column of water of unit cross sectional area can be expressed by

$$\frac{\partial z}{\partial t} = -\nabla(z\bar{v}) \text{ and } \frac{\partial(C_p z\theta)}{\partial t} = H - \nabla(C_p z\theta\bar{v})$$

which after expanding and combining reduce to

$$\frac{\partial\theta}{\partial t} = \frac{H}{zC_p} - \bar{v}\cdot\nabla\theta$$

In the above equations H is the net heat exchange across the sea surface (insolation less evaporation less back radiation less conduction), θ is the surface temperature, C_p is the specific heat at constant pressure which can here be considered constant, z the depth of mixed layer, $\bar{v}$ the velocity, and ∇ the operator

$$\bar{i}\,\frac{\partial}{\partial x} + \bar{j}\,\frac{\partial}{\partial y}$$

The last equation, the temperature budget, states that the time rate of change of temperature and not the absolute temperature is of importance when processes are considered. The equation also points out that in order to understand the advection term $(\bar{v}\cdot\nabla\theta)$ the horizontal distribution of temperature about the locality of interest must be known. In other words, by knowing the horizontal temperature gradient, one can obtain a measure of the velocity component perpendicular to the isotherms. Finally, heat advection cannot give any information about the velocity component parallel to the isotherms.

A similar expression for the salinity budget in the surface layer is as follows:

$$\frac{\partial s}{\partial t} = \frac{s}{z}(E-P) - \bar{v}\cdot\nabla s$$

Here s is the salinity and $(E-P)$ the evaporation minus precipitation.

The above discussion as well as the approximate values of $\frac{\partial\theta}{\partial t}$ and $\frac{H}{zC_p}$ used below, will be presented with more detail in the climatic atlas which is in preparation for publication.

Of interest now are the graphs obtained when $\frac{\partial\theta}{\partial t}$ and $\frac{H}{zC_p}$ are plotted versus time as shown in figure 47A. The solid line shows the mean seasonal variation of the rate of change of surface temperature in the vicinity of Oahu, Hawaii, and the dashed line the seasonal rate of change of surface temperature due to the net heat exchange across the sea surface only. The difference between the two curves indicates advection.

Thus, when $\frac{H}{zC_p} > \frac{\partial\theta}{\partial t}$, the component of flow across the isotherms is from cold to warm, indicating cold advection. When $\frac{H}{zC_p} < \frac{\partial\theta}{\partial t}$, warm advection is indicated. No advection $\frac{H}{zC_p} = \frac{\partial\theta}{\partial t}$, indicates either flow parallel to the isotherms or no flow.

Figure 47A shows what may be called characteristic advection features for the vicinity of Oahu: low advection from February to May, and considerable advection for the remainder of the year.

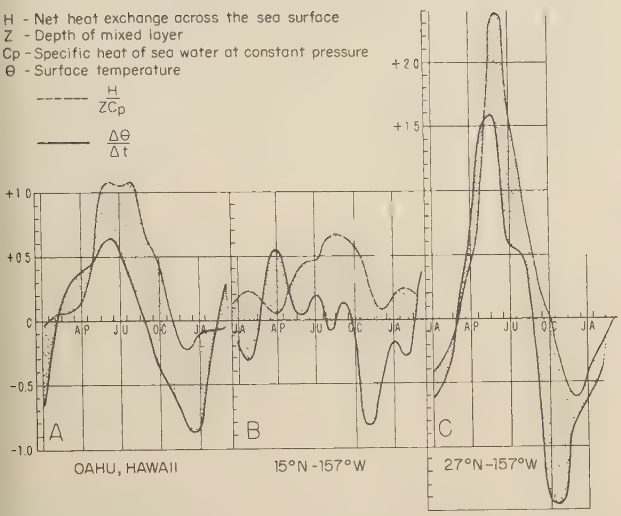

FIGURE 47. Characteristic heat advection curves.

Similar graphs can be drawn for other locations. For xample, figures 47B and 47C show the "characteristic eat advection curves" for 15°N. and 27°N. to the outh and north of Oahu, respectively. At 15°N. warm dvection occurs during March to May, the $\frac{\Delta\theta}{\Delta t}_{\max}$ d $\frac{H}{zC_p}_{\max}$ are four to five months out of phase, and ven the $\frac{\Delta\theta}{\Delta t}$ fluctuations between June and October e believed to be characteristic of the location.

The characteristic heat advection curve for 27°N. ig. 47C) shows that the period of low advection ex- nds from February to May and high advection from ctober to December, approximately as in the vicinity Oahu. However, the curves also reveal that the heat change across the sea surface plays a greater role in termining the surface temperature than it does rther to the south. In other words, advection is rela- vely less important in determining the temperature an is the heat exchange across the sea surface.

To illustrate how the characteristic advection curves ay be used to interpret local temperature anomalies, e mean Oahu temperatures and rates of change of mperature (solid lines) are drawn in figure 48 to- ther with the Koko Head values for 1956 and 1957 ashed line). Of interest in figure 48A are the below rmal temperatures February to June 1957, and again m December 1957 to April 1958. Also of interest are e below normal temperatures during November and ecember of 1955.

Figure 48B deviations from the mean pattern are brought out in terms of processes. For the sake of clarity the mean $\frac{H}{z}$ curve has been omitted from the graph. The $\frac{\Delta\theta}{\Delta t}$ curve shows that in December 1955 and January 1956 it was higher than the mean curve which can be interpreted as less cold advection. Then from February to April of 1956, the curve is below the mean which indicates an increase of cold advection during that period. September and October of 1956 indicated reduced cold advection. The $\frac{\Delta\theta}{\Delta t}$ curve for 1957 shows colder than normal advection between January and April and then, during May and June, considerable warmer than normal advection. Finally, during November and December colder than normal advection is again indicated.

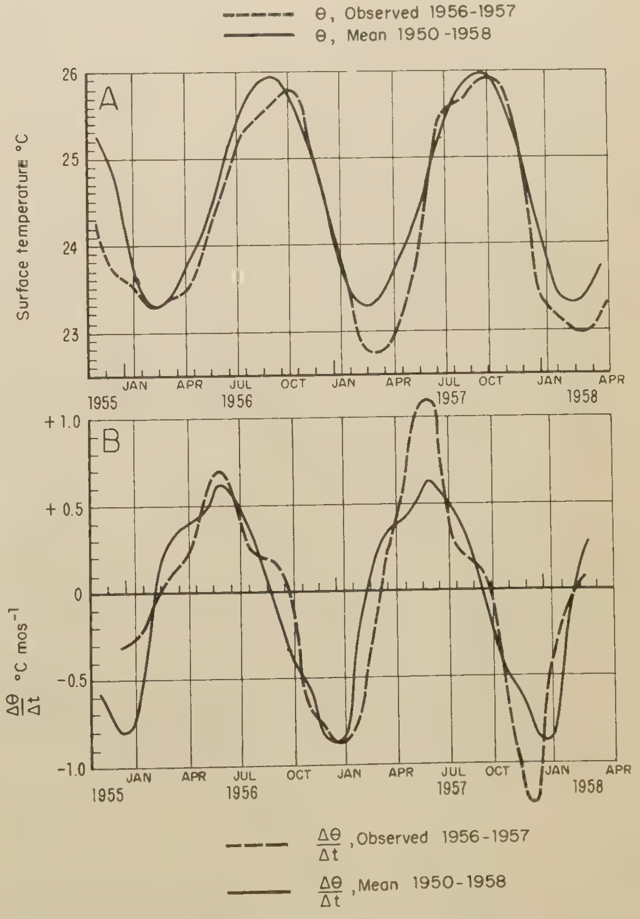

FIGURE 48. A. Mean and observed surface temperatures, Oahu, Hawaii. B. Characteristic and observed rates of change of surface temperature, Oahu, Hawaii.

When the 1957 $\frac{\Delta\theta}{\Delta t}$ curve is now compared to the mean or characteristic curve at 27°N. (Fig. 47C), a striking resemblance in the shape of the two curves becomes apparent. This suggests a southward shift of the oceanographic climate. Or, during 1957, Oahu found itself in an oceanographic climate normally to be found a few degrees of latitude to the north. This observation is in agreement with the salinity observations presented by Murphy et al.

Similar salt advection curves could add significantly to the climatic picture of a region. Unfortunately, our salinity data are too incomplete to enable an interpretation of the 1956, 1957 salinities in terms of salt advection at this time.

To summarize, characteristic heat advection curves illustrate two important climatic features:

1. Deviations from the mean $\frac{\Delta\theta}{\Delta t}$ curve as in 1956 can explain temperature anomalies in terms of heat exchange and advection, and, if the temperature gradients are also known, changes in the component of flow normal to the isotherms.
2. Changes in the characteristic $\frac{\Delta\theta}{\Delta t}$ pattern as in 1957 can reveal shifts in the oceanographic climate.

GENERAL REMARKS

The shortcomings in the above discussion lie in experimentally unverified interpretation of the $\frac{\Delta\theta}{\Delta t}$ curves and not in the use of such curves as tools in interpreting monitoring data. This is primarily due to the fact that one or more members of the budget equation are usually absent.

In order to be able to interpret characteristic advection curves with confidence, temperature and salinity measurements are insufficient to begin with. In the Hawaiian Islands region, the magnitude of the year-to-year variation of H and z must be determined as well as changes in the horizontal temperature and salinity gradients. In order to be able to verify the results, the velocity must also be determined.

We may discover that because of the buffering action of the sea the heat exchange across the sea surface shows little annual variation. We may also discover that the same is true for the horizontal gradients in many areas. We may find that although diffusion is not entirely negligible, the year-to-year variation of diffusion would be. Thus, characteristic advection curves could be used to interpret temperature and salinity anomalies in terms of shifts in oceanographic climate or changes in flow perpendicular to the isopleths. They could also be used to interpret past records where adequate time series are available.

ADDENDUM

In the discussion of figure 48B the deviation of the 1956-1957 observed $\frac{\Delta\theta}{\Delta t}$ curve from the mean $\frac{\Delta\theta}{\Delta t}$ curve was explained in terms of advection. This implies that $\frac{H}{z}$ and diffusion do not show year-to-year variations which, of course, is not reasonable. There are, however, data which suggest that year-to-year changes in these are insufficient to account for the $\frac{\Delta\theta}{\Delta t}$ deviations during 1956 and 1957.

In the vicinity of the Hawaiian Islands examination of the vertical temperature gradient below the mixed surface layer reveals no seasonal change. This suggests that the stability also remains constant and that therefore significant changes in the vertical diffusion are unlikely even if the diffusion is not negligible as assumed in the above discussion.

The seasonal range of the calculated heat losses from the sea surface (evaporation, back radiation, and conduction of sensible heat) is only about 5 percent. It is expected that the year-to-year changes in the heat lost from the sea surface are less.

Remaining is the incident radiation which can vary considerably due to changes in cloud cover. Although no observations are available at sea, the incident radiation has been measured on Oahu by the Hawaiian Sugar Planters Association and the Pineapple Research Institute.

Between 1943 and 1957 the greatest deviation of the incident radiation from the mean for the month of June has been less than ± 10 percent. Therefore, in June one might expect a change in $\frac{\Delta\theta}{\Delta t}$ of .1°C. due to a change in incident radiation. In winter when $\frac{H}{z}$ is small the year-to-year fluctuations in $\frac{H}{z}$ would result in a negligible change of $\frac{\Delta\theta}{\Delta t}$.

Going back to figure 48B, the deviations of the observed from the mean $\frac{\Delta\theta}{\Delta t}$ curve were approximately as follows:

December 1955—January 1956	+ .5°C.
February—April 1, 1956	— .15°C.
September—October 1956	+ .3°C.
January—April 1957	— .4°C.
May—June 1957	+ .5°C.
November—December 1957	+ .5°C.

These are well in excess of changes to be expected n changes in $\frac{H}{z}$ so that advection remains as the st likely process responsible for the 1956-1957 sea- face temperature changes in the vicinity of the waiian Islands.

SCUSSION

Charney: Before opening the discussion from the or, I wonder if I might use my prerogative as chair- n to ask a number of questions. Since I do not have proper background for absorbing oceanographic a in such large quantities, I feel that I have just out reached my saturation point and should like hear some explanations. Quite a number of events ve been reported and, as has been pointed out, we y be talking about phenomena on different scales. e examples presented by Mr. Murphy are a very od documentation of oceanographic changes. Atten- n has been concentrated on the temperature anoma- . May I ask questions about these anomalies? It ms to me that temperatures in the ocean can be nged by a number of mechanisms, some of which ve already been mentioned by Mr. Murphy. Any- ng that would interfere with the net heat flux at ocean surface would produce temperature anoma- . But variations in surface-heat flux do not in them- ves determine the anomalies. You have to know at is happening beneath the surface. In the central ions of the oceans the heat that is being absorbed the surface is at least partially balanced by the wnward flux into deep water: if you increase the wnward flux of heat beneath the surface, the tem- ature will fall, and conversely, if you decrease the wnward flux of heat, the temperature will rise.

Anything that would decrease the anticyclonic curl the wind stress would immediately, everything else ng constant, decrease this downward flux of warm ter and produce a warming. This is one mechanism. w important is it?

The next question is suggested by the data that ofessor Isaacs so kindly provided beforehand. At ods Hole we looked at the NORPAC current veloci- and temperature distributions and asked our- ves, "Can one account for the temperature in- ases, which are of the order of 2° or 3° F., in a atively short period, by advection of warm water?" ather from Mr. Murphy's remarks that there is a sibility of this too.

A third question is suggested by Mr. Namias' refer- e to a possible correlation between anomalous tem- ature changes in the oceans and anomalous tem- ature changes in the atmosphere, although he efully avoided the implication of a direct causal ationship. One can at least ask the question: to at extent are the temperatures in the ocean deter- ed by the atmospheric temperatures? I am under impression that the direct transfer of heat between atmosphere and the ocean is small and could not ount for the changes. If this is so, the influences st be more roundabout.

I do not presume to answer my own questions. They are questions, however, that I think are pertinent to the problems with which we are dealing here. And, I wonder if it makes any sense at this point, before we try to assimilate more data, to try to get some answers. Those who have presented the data have, of course, thought about answers to these or similar questions. By observation they have tried to establish direct physical relationships or to suggest the possibility of some mechanism or another. After all, we do have something to explain: enormous changes—anomalies of up to 6°F over a very wide area in the Pacific. These changes are rather sudden. From December to January, there are changes of 4 to 6°F. How does one account for these changes? Can one account for them by advection?

Fleming: Can I point out here that, in terms of total heat budget for the year, the changes in the heat of water are very, very small, compared to the other process of heat exchange. In other words, back radiation is so large compared say, to heat in the water, that I think you have to look for some process that is altering incoming radiation or evaporation. As has been said before, many of these are feedback mechanisms. I think you have to remember that you are looking at something that is probably a consequence, more than a cause.

Reid: Referring to one of your mechanisms—the temperature change which can be accounted for by wind curl—we do have measurements of temperature change but no computations of wind curl. We do have an index of pressure changes. When we consider the circulation of the winds and the known temperatures, we have found what appears to be in many cases, a relation between wind variations and temperature variations. We have a theory in mind but it is not necessarily a correct one.

Stommel: When you strengthen the California Current you do it by decreasing the wind curl.

Reid: And increased temperatures might be caused, among other things, by weaker winds as well as decreased wind curl.

Stommel: When you increase wind you have an increase in current and therefore a convergence to the right, and both of these could possibly change the water surface temperature.

Reid: Increasing the thickness of the mixed layer by stirring would cause cooling. In part of the Northern Pacific region, the wind strength is *inversely* related to the temperature, but in the Kuroshio it is *directly* related, in some seasons.

Charney: It would depend on how far down the mixing went.

Reid: We do have vertical sections across the California Current which show that in 1957 there was great warming in the mixed layer, and in some cases there appears to be a maximum in the extent of the warming just below the thermocline. The heat has not been merely redistributed so that the water is cooler below the thermocline than above. Enough additional heat has come in by some advective process to have warming below the thermocline as well as above.

Charney: Why do you say some advective process?

Reid: Because I have in mind a tentative hypothesis involving advection, which is consonant with the recent changes in the California Current system.

Charney: What about the stirring downwards of the heated layer?

Munk: I was going to say that maybe to some extent you can reason from an analogy with the seasonal effect as we are talking about a three months abnormality of weather. Dr. June Pattullo, for a doctor's degree, tried to work out a heat budget of the world on a seasonal basis and found out that for most of the world, the changes in heat content are limited to the upper layers. One can use the flux and ignore advection, and come out quite well. That tends to bear out Dr. Fleming, in that there is plenty of flux in and out.

Fleming: Also, I think while we are discussing this, a number of people have tried to evaluate these processes and they never succeed. You really can not evaluate all the factors. We have tried to account for the annual cycle of temperature. Gunter Seckel has been working with data around Honolulu, but you really cannot evaluate these things because there are too many unknowns. For example, in terms of the advection, you nearly always have horizontal gradients, but you do not know the direction of the flow well enough to know what component to put in to evaluate the advection.

Charney: But I gather from those remarks that if you simply made the assumption that there was a little advection, you could account for the changes.

Fleming: If you take the whole North Pacific.

Munk: If you could take the heat content (not temperature) of all oceans, then, of course, you have no advection. Only the flux through the surface is important—evaporation, radiation, etc. For even small units, advection might be a comparatively small factor. Dr. Pattullo took one gyre at a time and did pretty well by simply assuming no advection in and out of the gyres.

Charney: If you consider the seasonal mean, would it be possible to take the wind data and compute the mean Ekman convergence, which would give the flux of heat through the bottom of the wind-stirred layer? It seems to me that other things being equal, this would then give the anomalous temperature changes as well as the heat content changes. Of course we are only talking about superficial aspects. In other words, I do not think of this mechanism as determining the heat supply but only as determining changes in the surface layers. It may have little to do with the overall heat budget of the oceans.

Schaefer: If you know the change in heat content because you have measured it, from what do you compute this flux?

Charney: I may be all wrong and I hope someone will correct me if I am, but here is my reasoning: assume that the Coriolis force in the wind-stirred layer is balanced by the pressure force and the force
friction due to vertical eddy transfer of momentu

$$f\,\vec{k}\ X\ \rho\,\vec{v} = -\ \nabla_h p + \frac{\partial\vec{\tau}}{\partial z}.$$

Take the curl and integrate through the entire dept
h of the windstirred layer. One obtains approximatel

$$f\int_{-h}^{o} div_h\ (\rho\,\vec{v})\ dz\ =\ \text{curl}\ \vec{\tau}_o;$$

From continuity

$$div_h\ (\rho\,\vec{v}) \cong -\ \frac{\partial(\rho w)}{\partial z}\ .$$

Whence

$$f(\rho w)_{z\ =\ -h} = \text{curl}\ \vec{\tau}_o,$$

which states that the mass transport ρw at the botto
of the stirred layer is equal to the curl of the surfa
wind stress divided by the Coriolis parameter. If t
temperatures at this level are assumed to be know
the heat transport is thereby determined. This
essentially a mid-ocean up or downwelling effect.

Schaefer: Are you going to measure this quanti
on the right from the pressure charts, and compu
the vertical flux of heat?

Stommel: From a dynamic point of view, would
not be more constructive if you could use mixed lay
depth rather than surface temperatures? That is wh
Seckel did.

Isaacs: But there was an increase in heat below t
thermocline off California, and one of Seckel's a
sumptions was a negligible heat transfer vertical
through the thermocline.

Schaefer: Rather than depend on a wind stress
compute heat transfer, Seckel used the total heat co
tent of the water column. He measured this direct
One factor is bothersome here. You have three pr
esses—advection, changes in incoming and changes
back radiation. The bothersome thing is back radi
tion. You either have to assume it to be a consta
or measure it. For incoming radiation and back radi
tion, you wind up using some average for t
Northern Hemisphere—values that do not apply
the particular area you are working with.

Charney: Is this a small difference between tw
large terms?

Schaefer: It is the difference between two relative
large terms. You do not know them for the exact da
you are working with, and you assume some sort
average.

Saur: Roden, did you not make some calculatio
on the heat transport of the California Current? A
did these not show a loss of up to 400 gram calori
per day per square centimeter?

Roden: On an annual average the incoming radi
tion is about 400 cal per cm^2 per day. The back radi
tion is about 100 cal per cm^2 per day. The loss of he
through evaporation is about 100 cal per cm^2 per da

his leaves 200 cal per cm^2 per day for the advection rm, and the advection must be of cold water. Since diation varies only by a factor of two in different ars, and wind by as much as a factor of five (and ress as the square of this, Eds.), I think that heat anges are more likely to be caused by wind changes an by radiation changes.

Namias: One of the effects perhaps resulting from rtical motion, particularly in some of the areas of gures 21 and 22, was a particular dramatic change a sharp negative anomaly in a short period of time. ssociated with this was a sharp increase in cyclonesis, which might account for a lowering of surface mperature. Over the easternmost area the temerature rise is confined, as I see it, mostly to the east de of a negative air pressure anomaly (Fig. 7) here there are these anomalous southerly components wind presumably, resulting in warm water roughout the mixed layer. On the other side of the egative anomaly no such increase is true, as the nomalous components are from the other direction.

Roden: I think that the negative pressure anomaly ill have opposite effects on opposite sides of the cean. We have observed an increase in surface temeratures in the Northeastern Pacific and a decrease the Northwestern Pacific.

Takenouti: North of the Kuroshio zone in Japan in 955, there was also high temperature at this point. 1955 was a year of cold in the eastern North Pacific. ds.)

Munk: In Hawaii do you observe great changes in salinity? I thought they were greater than temperature. In 1958 there was a marked rise in temperature, and a rise in salinity more marked than the rise in temperature. It must mean advection does it not?

Murphy: This was our interpretation.

Reid: And, further strengthening our belief in advection off California, we had significant decreases in sub-thermocline oxygen. There were extremely low oxygens off the coast of California, about 0.5 milliliters per liter less than average, and it is difficult to account for these subsurface changes in oxygen except by advection.

Favorite: I am wondering if insolation would account for the change you attribute to advection. Do you have that much confidence in the insolation values?

Reid: What we have here is too primitive for that. We have temperature measurements which allow us to make temperature anomaly charts over a certain area of the ocean. And there exists a somewhat similar distribution of the pressure anomalies for the period. We put these two sets of charts together—the pressure anomalies and temperature anomalies, and conclude that the pressure anomalies indicate an anomalous wind, which might result in moving water to effect the observed temperature anomalies.

Schaefer: The supposed changes in advection are so great that I do not think that they could be accounted for by errors.

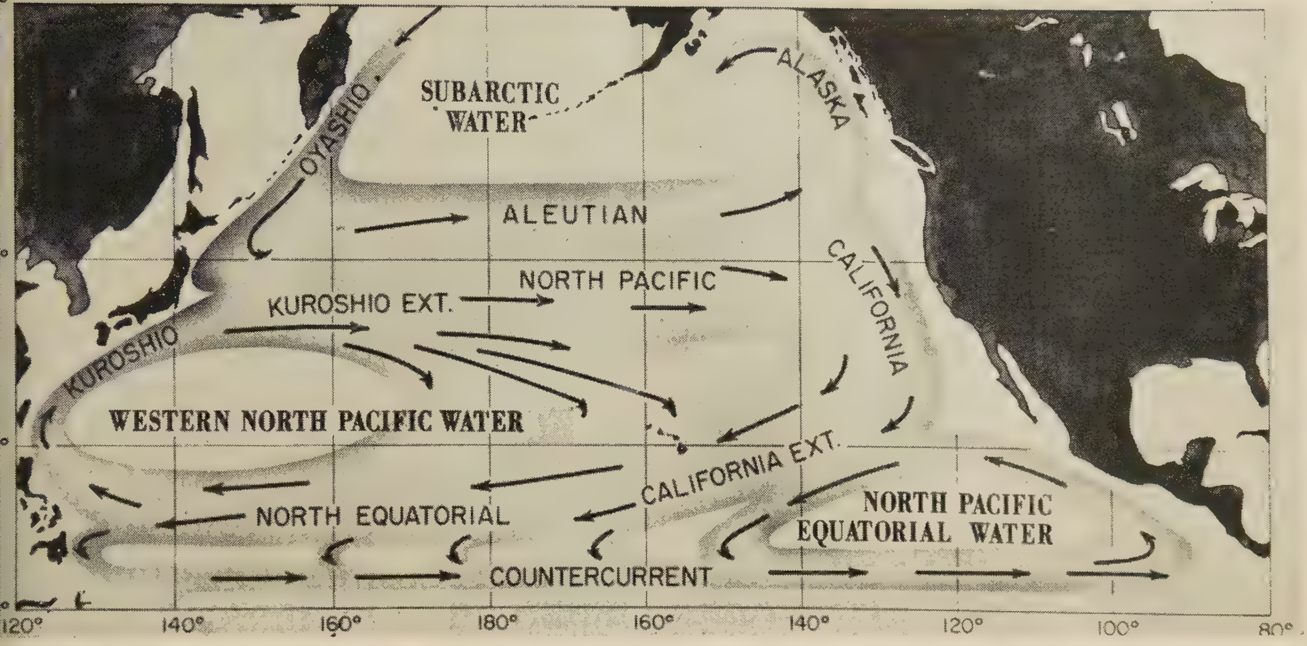

Figure 1.—The major surface current systems in the North Pacific Ocean.

OCEANOGRAPHY and the HAWAIIAN SKIPJACK FISHERY

By
NTER H. SECKEL
nd
NNETH D. WALDRON

n March, 1959, the prediction was le to the tuna industry that the 9 Hawaiian Skipjack season would better than average and that the h might approach the 14 million nds landed in 1954. Actual 1959 lings of 13 million pounds sub-tiated the forecast.

his prediction was a by-product of environmental study in which cer- processes in the ocean were dis-ered to be associated with varia-s in Skipjack landings. The high-ts of the investigation and some of implications will be discussed w.

nnual Skipjack catches from Ha-an waters since 1948 have varied veen 6 million pounds in 1957 and nillion pounds in 1954. The landings are seasonal with monthly catches of less than 100,000 pounds during the winter and over 2,500,000 pounds during the summer.

Small Skipjack are present in island waters throughout the year, but the success of the summer season depends upon a high availability of 20-30 pound fish. The fluctuations in landings since 1948 appear to have been due largely to the unexplained variations in availability of these large fish.

The fishery is conducted within a relatively restricted area, which seldom extends beyond 100 miles from land. This contributes to the variations in landings, for low catches in local waters are not balanced by catches from surrounding areas, as is the case in other fisheries. Because the fleet does not range widely, fluctuations in landings are thought to reflect changes in the availability of Skipjack in Hawaiian waters.

The Hawaiian Skipjack fleet has undergone only one recent major change in numbers, and this was a result of two successive poor years, 1957 and 1958. The fleet that fished during 1956 consisted of 28 boats. Only 21 of these fished during 1959, a reduction of 25 percent. During this same period, effort was reduced still further by fishermen leaving the industry. In light of this reduction in effort, the successful 1959 prediction is even more significant.

The seasonal and annual variations in Skipjack landings are a source of economic hardship for both the fishermen and the processors. It is therefore important to investigate the causes, and if possible, predict these fluctuations in advance of the fishing season.

● In the belief that fluctuations in the fishery were associated with changes in the environment, an oceanographic study was initiated. This showed that the Hawaiian Islands are located in the vicinity of a boundary separating two water types, as schematically illustrated in Figure 1. To the north and west is the western North Pacific type, with a salinity of more than 35 parts per thousand (3.5 per cent). To the south and east is the transition type of the California Current Extension, with a salinity of approximately 34.7 parts per thousand (3.47 per cent). It was found that this boundary, which is located just south of the islands during the winter months, begins to move northward early in the year. It passes through the islands in

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TE—Mr. Seckel is Oceanographer Mr. Waldron Fishery Research ogist on the staff of the Hono- Biological Laboratory, U. S. Bu- of Commercial Fisheries, Hono-, Hawaii.

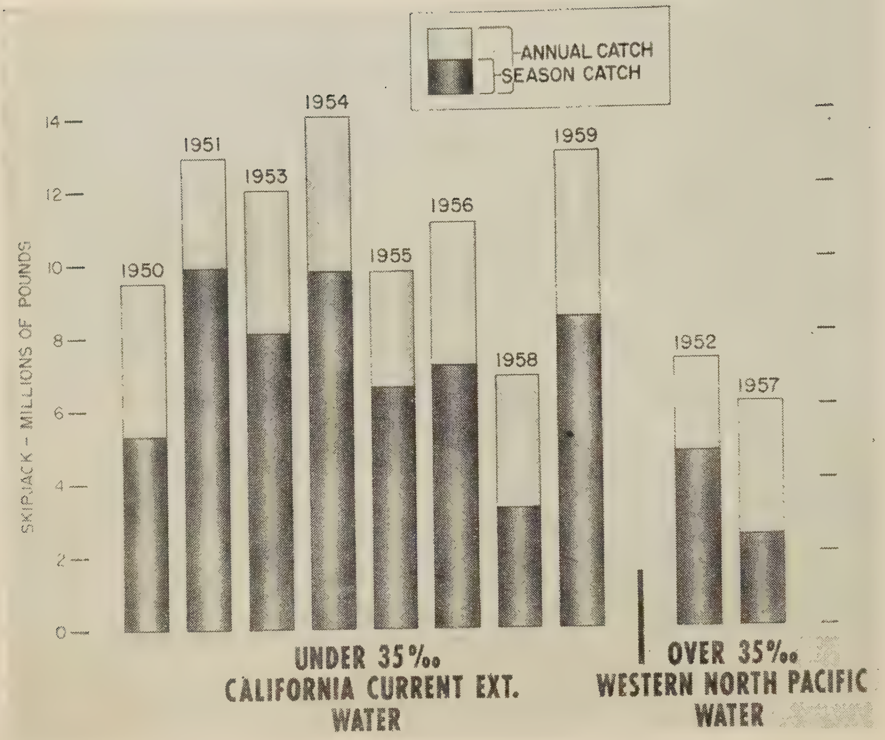

Figure 2.—Hawaiian Skipjack landings as related to the summer salinity of the ocean near Oahu.

April or May and brings the lower salinity water of the California Current Extension. This process is reversed in August, when the boundary begins its southward retreat. It then passes the islands in October or November and brings the high salinity water of the western North Pacific.

The spring movement of the boundary, bringing California Current Extension water into the island area, appears to be associated with the success of the Hawaiian skipjack fishery, as illustrated in Figure 2. Whenever California Current Extension water bathes the islands during the summer, as indicated by salinities of less 35 parts per thousand, the annual Skipjack landings have, with the exception of 1958[1], been average or better than average. Whenever the salinities were higher than 35 parts per thousand, as in 1952 and 1957, the annual landings were less than average.

From these results one can postulate that commercial quantities of Skipjack appear in the islnad area together with the California Current Extension. One can also postulate that there are years in which the California Current System fails to intensify sufficiently to move the boundary into and through the island area. During such years fishing is likely to be poor.

● These ideas about the association between fishing success and oceanography in the Hawaiian Islands as obtained from salinity observations, are also supported by temperature studies. Early and rapid warming of the water near the island of Oahu, as the boundary begins to move northward, appears to be associated with a well developed California Current System. This is usually followed by a decrease in the rate of warming, or even a slight cooling as the boundary passes through the islands. These features were most pronounced in 1954 and 1959, the best postwar fishing years with landings of 14,000,000 and 13,000,000 pounds, respectively.

Of particular interest to the fishing industry is the early warming of the water prior to the fishing season and the fact that this can be monitored by observing surface water temperature. The upper panel of Figure 3 shows that at Koko Head, Oahu, the temperature reaches a minimum during the end of February. It can also be seen that when the water begins to warm the temperature does not rise uniformly. From March to April it rises .4°C., from April to May .3°C., from May to June it rises almost 1°C.

These features become more apparent if one draws the monthly rate of change of temperature as shown in the lower panel of figure 3. Here, when the curve is zero at the end of February, the minimum temperature has been reached and warming begins. This means that the boundary between the western North Pacific and the California Current Extension types of
water is beginning to move northwa
One also notes that the rate of war
ing decreases from .4°C. at the beg
ning of April to .3°C. at the beginni
of May. This signals the time wh
the boundary moves through the
land area. Using sea water tempe
tures from the Koko Head stati
therefore, one can detect the beg
ning of the northward movement
the boundary even though it is
cated to the south of the islands.

In Figure 4 we see that the time
the northward movement of t
boundary is related to the annual Sk
jack landings. Whenever this occur
in February, which implies a well
veloped California Current System,
erage or better than average fish
years occurred. Northward movem
of the boundary beginning in Mar
which implies a weak California C
rent System, was associated with
annual landings.

● The results of this investigation
dicate that both the seasonal and
nual variations in the occurrence
Skipjack within the island region
indeed associated with environme
changes. As yet, however, we do
know what environmental factors
rectly influence Skipjack moveme
Our lack of knowledge of these f
tors constitutes an element of un

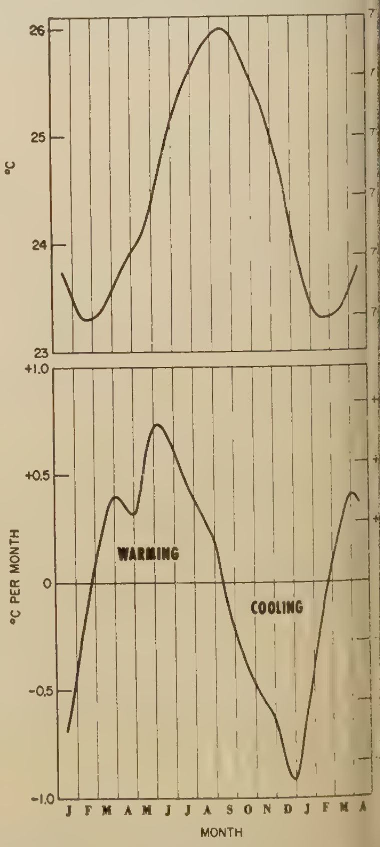

Figure 3.—Average sea water t
peratures at Koko Head, Oa
upper panel. Average monthly
of change of temperature at K
Head, Oahu—lower panel.

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*In 1958 the minimum summer salinity of 34.9 parts per thousand resembled the western North Pacific water more closely than the 34.7 parts per thousand of the California Current Extension.

ty in the prediction. This is knowl- e we must have if we are to fully erstand the relationship and thus ably predict the degree of availa- y of Skipjack in the Hawaiian Is- ds area during the fishing season.

everal years ago an attempt was le to predict the season (May to gust) catch on the basis of the ngth of the trade winds earlier in year. The prediction showed prom- but then failed, probably because trade winds are only one factor in circulation of the North Pacific. ilarly, a well or poorly developed ifornia Current System may not ays be preceded by the temperature nges noted at Koko Head during past nine years.

t should be pointed out that the dictive relationship is between nges in the physical environment landings made later in the year. consideration is given to changes the magnitude of the Skipjack ks on which the Hawaiian fishery ased. The fact that an excellent re- onship obtains might indicate that nges in the magnitude of Hawaiian jack stocks from such causes as ll year-classes or varying amounts harvest by the fishermen are not of or importance. If the physical en- nment is of favorable character, jack should be plentiful in the vaiian area. If the environment is avorable, few Skipjack of the size ally associated with a good season appear in the island waters.

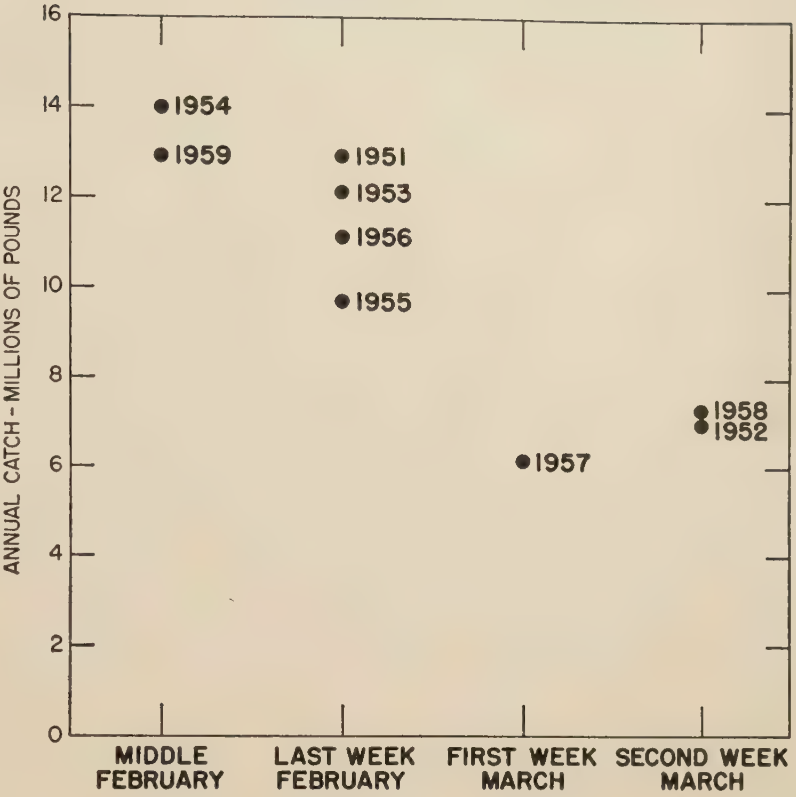

Figure 4. — Hawaiian Skipjack landings as related to the time of spring warming of the ocean at Koko Head, Oahu.

he true value in this investigation not primarily lie in the discovery prediction index but in gaining erstanding both of the Skipjack of the processes in their physical ronment. By continuing this approach, we hope to eventually know what factors are responsible for the concentration of Skipjack when the island area is bathed in California Current Extension water.

While the recognition of an apparent association between certain environmental features and the success of the Skipjack fishery was not an entirely unexpected result, it is to be doubted that such a prediction would have been obtained had the investigation been conceived with this as its primary goal. It was designed primarily to help us understand the local oceanographic climate. It may be anticipated that this understanding, when strengthened and extended by future investigations, will find usefulness in other areas, thereby accelerating the fruitful application of science to fisheries on a broad basis.

A New Hawaiian Engraulid Fish

DONALD W. STRASBURG

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October, 1960

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A New Hawaiian Engraulid Fish

DONALD W. STRASBURG[1]

THE OCEANIC SKIPJACK or aku (*Katsuwonus pelamis*) is commercially the most important fish in the Hawaiian Islands. This tuna is captured by pole and line, using live bait as chum. Of the several species of small fish employed as bait, the endemic anchovy known as nehu (*Stolephorus purpureus,* family Engraulidae) forms the major skipjack bait resource. Its importance in this respect has made the nehu the subject of several studies, resulting in reports on its food habits (Hiatt, 1951), spawning (Tester, 1951, 1955), oxygen requirements (Pritchard, 1955), meristic variation (Tester and Hiatt, 1952), and taxonomy (Gosline, 1951). Biologically, the nehu is probably the best-known fish in the Hawaiian Islands.

The nehu is a carnivorous anchovy, living and breeding in estuaries and bays. It is captured by seine during the day, and by a combination of seine and electric light at night. The nehu has been regarded as neritic except for two puzzling circumstances: the nehu population in Maalaea Bay, Maui, is periodically augmented by incursions of fish apparently from the open sea, and eggs differing only slightly from those of nehu were once taken in the offshore waters of Oahu (Tester, personal communication).

During the summer of 1958 the research vessel "Charles H. Gilbert" of the U. S. Fish and Wildlife Service encountered several large schools of anchovies 5–30 mi. off Oahu. Samples were presumed to be nehu and were not preserved. Later, conversation with commercial fishermen revealed that, while not regularly occurring, such schools were not rare, and also that the fish differed from nehu in both color and shape. Some fishermen termed these fish "oki-iwashi," which is literally translated as "pelagic sardine-like fish," while others referred to them as "roundheads." The latter name was descriptive of the short head which caused the fish to be gilled in seines used for nehu.

Thinking that this offshore anchovy represented either a different species or an ecological variant of nehu, we intensified our efforts to obtain specimens from areas removed from the inshore nehu grounds. Ultimately, two small collections were obtained, one through the interest of Captain Noboru Tsue of the M/V "Buccaneer," the other from biologists of the Territorial Division of Fish and Game (Honolulu). Examination of these specimens proved them to be not only distinct from nehu but also new to science. It is the purpose of this paper to describe and distinguish this new Hawaiian anchovy.

In addition to the collectors, thanks are due also to Drs. Albert L. Tester and William A. Gosline of the University of Hawaii, the former for making available meristic data for nehu, the latter for examining specimens of *Anchoviella mauii.* I am also grateful to Mr. John G. Simpson of the Inter-American Tropical Tuna Commission for data on Central American *Anchoviella.*

METHODS

All meristic data were enumerated from specimens stained with alizarin. Articulated and nonarticulated fin rays were not differentiated, and those rays split to a single base were counted as single rays. All gill rakers, including rudiments, were counted from the first arch on the right side. Distinction between the upper and lower limbs of gill arches was made on the presence of 1–3 rakers with bases embedded in connective tissue between the two portions of the arch. Because most specimens had lost their scales, the number of scale rows was obtained by counting the scale pockets. The only measurement needing description is maxillary length, which was taken as a straight line between the

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[1] U.S. Fish and Wildlife Service, Honolulu, Hawaii. Manuscript received February 4, 1959.

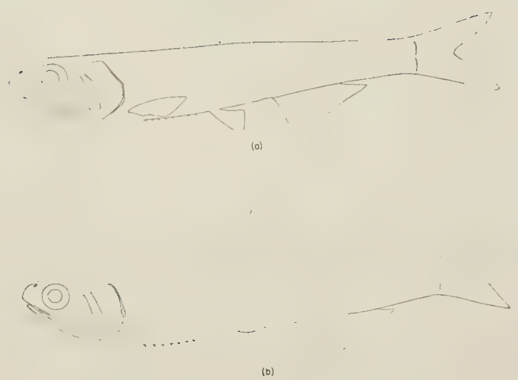

FIG. 1. Distinguishing features of Hawaiian engraulid fishes. Compare head length, maxillary length, and pectoral–pelvic interspace. *a, Stolephorus purpureus; b, Stolephorus buccaneeri.*

snout tip and the most posterior portion of the maxillary.

In a recent paper on the scientific name of the nehu, Gosline (1951) mentioned several problems incidental to the use of the term *Stolephorus,* and pointed out the need for a comparison between this genus and the related *Anchoviella.* Although both species of Hawaiian engraulids are referable to *Stolephorus* (Gosline, 1951; Weber and de Beaufort, 1913; Jordan and Seale, 1925, 1926), it is desirable to define this genus as exclusively as possible, for it has not been possible to undertake the needed study of the several engraulid genera. As it is here understood, *Stolephorus* includes those engraulid fishes having separate anal and caudal fins, the dorsal origin anterior to that of the anal, normal upper pectoral rays, bony scutes on the mid-ventral line, maxillaries not extending posterior of the gill opening, and a silvery stripe lengthwise on the body. The genus lacks canine teeth and free spines preceding the dorsal fin (spines are sometimes present in *S. tri* and *S. baganensis* (Hardenberg, 1933*a*)). As far as is known, the species of *Stolephorus* are Indo-Pacific in distribution. The Hawaiian forms can be distinguished from each other by characteristics presented in the following key, Figure 1, and Table 1. Differences between the new species and its congeners are mentioned in the species diagnosis.

KEY TO THE HAWAIIAN ENGRAULIDAE

1. Pectoral and pelvic fins far apart, distance between tip of depressed pectoral fin and pelvic base equal to twice eye diameter; maxillary short, failing to reach anterior edge of preopercle by a distance equal to ½ to ⅔ pupil diameter, maxillary length contained in head length 1.4–1.7 (usually 1.6) times; head short, its length contained 4.1–4.7 (usually 4.1–4.5) times in standard length........................Roundhead.
   Stolephorus buccaneeri, new species
2. Pectoral and pelvic fins close together, distance between tip of depressed pectoral and pelvic base equal to ¼ to 1 eye diameter; maxillary long, just reaching anterior edge of preopercle, its length contained in head length 1.0–1.3 (usually 1.3) times; head long, its length contained 3.4–4.0 (usually 3.5–3.8) times in standard length ....Nehu.
   Stolephorus purpureus Fowler

Stolephorus buccaneeri, new species
Figs. 1, 2

HOLOTYPE: USNM no. 177742, a male, 53.3 mm. in standard length, taken by seine 200 yd. west of Lehua Island, Niihau, Hawaiian Islands, on September 15, 1958, by Captain Noboru Tsue and crew of M/V "Buccaneer" of Honolulu.

PARATYPES: USNM no. 177743, 19 specimens, males and females, 44.7–58.9 mm. in standard length, taken with holotype; USNM no. 177744, 8 specimens, 40.5–51.5 mm. in standard length, taken from stomach of *Euthynnus yaito* captured 1 mi. off Makua, Oahu, Hawaiian Islands, on September 10, 1958, by Territorial Division of Fish and Game biologists aboard the M/V "Makua" of Honolulu.

DESCRIPTION: Counts made on *S. buccaneeri* are recorded in Table 1, and detailed measurements of the holotype and two paratypes appear in Table 2. Dorsal rays 13 or 14; anal 14–16, the last base usually with 2 rays; pectoral 14–17; pelvic 7; principal caudal rays 9 + 1 + 9; branchiostegal rays 11–13; gill rakers 16 or 17 + 2 or 3 + 23 or 24 (total 41–43); scales in a longitudinal series 41–44, in a transverse series 9(?) or 10(?); scutes on mid-ventral line

TABLE 1
COUNTS MADE ON HAWAIIAN SPECIES OF *Stolephorus*[1]

	DORSAL RAYS		ANAL RAYS		PECTORAL RAYS		PELVIC RAYS		PRINCIPAL CAUDAL RAYS, *buccaneeri*	BRANCHIOSTEGAL RAYS, *buccaneeri*	SCALE ROWS		VENTRAL SCUTES		GILL RAKERS	
	buccaneeri	*purpureus*	*buccaneeri*	*purpureus*	*buccaneeri*	*purpureus*	*buccaneeri*	*purpureus*			*buccaneeri*	*purpureus*	*buccaneeri*	*purpureus*	*buccaneeri*	*purpureus*
0....	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—	—
1....	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
2....	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
3....	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—
4....	—	—	—	—	—	—	—	—	—	—	—	—	14	3	—	—
5....	—	—	—	—	—	—	—	—	—	—	—	—	5	1	—	—
6....	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—
7....	—	—	—	—	—	—	19	40	—	—	—	—	1	—	—	—
10....	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
11....	—	1	—	—	—	—	—	—	—	9	—	—	—	—	—	—
12....	—	8	—	—	—	10	—	—	—	7	—	—	—	—	—	—
13....	21	126	—	—	—	77	—	—	—	3	—	—	—	—	—	—
14....	9	82	6	5	17	175	—	—	—	—	—	—	—	—	—	—
15....	—	2	19	55	18	65	—	—	—	—	—	—	—	—	—	—
16....	—	—	5	113	7	11	—	—	—	—	—	—	—	—	—	—
17....	—	—	—	43	2	2	—	—	—	—	—	—	—	—	—	—
18....	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—
19....	—	—	—	—	—	—	—	—	22	—	—	—	—	—	—	—
38....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
39....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
40....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
41....	—	—	—	—	—	—	—	—	—	—	1	1	—	—	2	2
42....	—	—	—	—	—	—	—	—	—	—	3	2	—	—	3	11
43....	—	—	—	—	—	—	—	—	—	—	1	5	—	—	5	14
44....	—	—	—	—	—	—	—	—	—	—	1	3	—	—	—	35
45....	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	41
46....	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	36
47....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	25
48....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18
49....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	16
50....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7
51....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2

[1] Most data for *purpureus* were supplied by Tester. Both pectoral and pelvic fins were counted, except for the pectorals of some *purpureus*.

2–7 (usually 3–5); vertebrae 43 including urostyle (1 specimen).

Head 215–257, snout 44–59, bony interorbital 48–58, postorbital head length (horizontal) 100–130, maxillary length 141–168, eye diameter 54–79, snout to dorsal origin 473–534, snout to anal origin 672–730, snout to pelvic base 431–504, snout to anterior pectoral base 220–264, longest dorsal ray (2nd or 3rd ray) 119–168, longest pectoral ray 114–145, maximum depth 152–208, least depth of caudal peduncle 75–98, maximum width 112–140 (all measurements as thousandths of the standard length, based on 22 specimens).

Teeth fine, noncaninoid, uniserial on premaxillary, maxillary, and mandible, in small patches and rows on palatines and hyoids, reduced to asperities on vomer; head naked, skin rugose in parietal region; opercle and preopercle without spines; pseudobranchiae well developed; both surfaces of gill rakers finely denticulate; mouth relatively small; posterior tip of maxillary smoothly rounded dorsally, truncate ventrally, failing to reach anterior margin of preopercle by ½–⅔ pupil diameter; posterior tip of mandible bluntly pointed, just reaching anterior edge of preopercle; ventral profile slightly curved, the ventral mid-line moderately compressed; scutes restricted to region between pectoral and pelvic fins, each with a posteriorly projecting spine and a riblike lateral ramus nearly reaching a pleural rib; caudal forked, the sixth ray from the top and bottom with a fleshy alar flap.

Scales deciduous, cycloid, with 11–13 radiating striae, the anterior 2 or 4 sometimes connecting centrally; anterior scale margin not crenulate; anterior half of scale with fine, parallel, dorsoventral grooves, posterior half with coarse crescentic grooves; an elongate alar scale above pectoral base, none (?) at pelvic base.

Ovarian eggs from a 49.3 mm. maturing female were oval and measured about 0.5 by 0.3 mm. These eggs were whitish and opaque and showed no signs of an oil globule when stained with Sudan IV.

Color in formalin straw or white with a silvery band lengthwise from eye to caudal base, band about ⅔ eye diameter in width at eye and on caudal peduncle, but as wide as eye beneath dorsal fin; tips of snout and mandible blackish, a spray of fine black dots on occipito-parietal region; dorsalmost scale pockets margined in black, particularly on caudal peduncle; dorsal and caudal rays black-spotted, a row of 14 or 15 black spots along anal base.

In life *buccaneeri* is said to be purplish blue, in contrast to *purpureus* which is greenish or brownish.

AFFINITIES: Comparative material of the numerous species of *Stolephorus* was not available, and the relationships of *buccaneeri* were determined almost solely from the literature. All nominal species referable to the genus (as defined above) were considered insofar as possible, but some poorly described forms could not be allocated, nor did descriptions always agree between authors. The authors cited below provided the information by which the species were separated. The order of presentation is not necessarily phylogenetic nor fully dichotomous.

TABLE 2

MEASUREMENTS, EXPRESSED IN THOUSANDTHS OF THE STANDARD LENGTH, MADE ON *Stolephorus buccaneeri*

	HOLOTYPE	PARATYPE	PARATYPE
Standard length (mm.)	53.3	49.8	55.3
Head length	250	215	230
Postorbital length of head	140	124	121
Eye diameter	67	60	54
Interorbital width	51	52	51
Snout length	46	48	49
Maxillary length	164	147	141
Maximum depth of body	187	169	181
Least depth of body	79	76	78
Maximum width of body	137	116	132
Snout to dorsal origin	529	488	528
Snout to anal origin	717	701	691
Snout to pectoral base	258	255	241
Snout to pelvic base	492	452	472
Longest dorsal ray	142	147	134
Longest pectoral ray	105	135	127
Sex	male	female	male

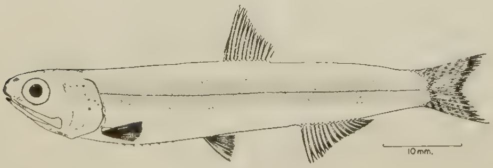

FIG. 2. Holotype of *Stolephorus buccaneeri*, new species (USNM no. 177742) from Lehua Island, Niihau, Hawaiian Islands.

Probably most distantly related to *buccaneeri* are those species of *Stolephorus* having the maxillary extending to the gill opening or nearly to it: *commersoni, waitei, rex, tri, baganensis,* and *insularis* (Jordan and Seale, 1926; Weber and de Beaufort, 1913; Fowler, 1941; Hardenberg, 1933*b*). Another distinctive group includes *evermanni* and *indicus,* both of which have the pectorals reaching or nearly reaching the pelvic bases (Jordan and Seale, 1906, 1926). According to Weber and de Beaufort (1913), the pectoral fins of *indicus* do not reach the pelvic base, but in their material the anal origin was below the middle of the dorsal base, whereas in *buccaneeri* the anal origin is slightly posterior to the rear of the dorsal base. *S. insularum, extensus, holodon, chinensis, nasuta,* and *aestuaria* differ from *buccaneeri* in having 20 or more anal rays (Jordan and Seale, 1926; Fowler, 1941);

and *heterolobus, pseudoheterolobus, zollingeri,* and *purpureus* differ in having the maxillary length contained 1.0–1.4 times in the head length, as opposed to 1.4–1.7 times for *buccaneeri* (Hardenberg, 1933*b;* Fowler, 1941). *S. celebicus* is listed by Hardenberg (1933*a,* 1933*b*) and Fowler (1941) as lacking scutes, and would therefore be excluded from this discussion were it not for the fact that *S. commersoni* occasionally also lacks these structures (Hardenberg, 1933*a*) as does *purpureus* (Table 1). The phylogenetic importance of scutes has been stressed by Jordan and Seale (1925, 1926), but it appears that their variation must be understood before they can be used to effect generic separation.

Some mention must also be made of *Anchoviella mauii.* Although described as new from Maui, Hawaiian Islands (Fowler and Bean, 1923), this species has since been synonymized with *Engraulis australis* by Fowler (1934), who also pointed out that the specimens were mislabeled as to locality.

DISTRIBUTION: *S. buccaneeri* has been collected only from the waters off the northern Hawaiian islands of Oahu and Niihau, and its true distribution is unknown. It also remains to be demonstrated whether schools of offshore anchovies are composed of *buccaneeri* or of *purpureus* or of both. Examination of a collection of anchovies from Maalaea, Maui (where the population is thought to be augmented from offshore stocks), revealed only *purpureus.* Judging from the place of capture of one type series (200 yd. from shore), *buccaneeri* also may be neritic.

REMARKS: It is a pleasure to name this new anchovy *buccaneeri* after the M/V "Buccaneer" of Honolulu. It is suggested that "roundhead" be used as a common name to distinguish this fish from nehu.

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ESTIMATES OF LARVAL TUNA ABUNDANCE IN THE CENTRAL PACIFIC

BY DONALD W. STRASBURG

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From Fishery Bulletin of the Fish and Wildlife Service
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CONTENTS

Page

Introduction ---- 231
Methods ---- 231
  Collecting ---- 231
  Processing ---- 233
  Identification ---- 233
  Terminology ---- 233
Reliability of a single sample ---- 233
Variations in the distribution of larval tuna ---- 235
  General vertical distribution ---- 235
  Diurnal variation in shallow-tow catches ---- 239
  Relation of larval tuna to invertebrate plankton ---- 241
  Length distribution of larval tuna by depth and time ---- 242
Adult versus larval tuna abundance ---- 244
Summary ---- 246
Literature cited ---- 247
Appendix ---- 249

ABSTRACT

Certain aspects of larval tuna sampling were studied by an analysis of the catches of the 0, 0–60, 70–130, 140–200, and 0–200 meter plankton tows made on 15 cruises in Hawaii, the equatorial Pacific, and French Oceania. The use of paired nets showed that the catch of a single net could be duplicated, and that plankton nets were therefore reliable tools for sampling the abundance of tuna larvae.

Most larval tuna were captured between the surface and 60 meters, with 20–25 percent more between 70 and 130 m., and practically none between 140 and 200 m. Marked night-day differences in catch occurred at the surface but became less at greater depths. Most of these differences were attributable to vertical migration rather than net-dodging. The 0–200 m. tow, fishing through the entire depth range of larval tuna, was regarded as the best of the tows tested.

Larval skipjack and frigate mackerel were rarely captured during the day by the 0 and 0-60 m. tows, but this was not true for yellowfin. Both skipjack and yellowfin began to appear at the surface in the afternoon but disappeared at sunset, to reappear somewhat later. This disappearance from the surface was correlated with the rise of the deep scattering layer.

The dominant size group in the larval tuna catch measured from 4.0-4.9 mm. total length. Many larvae of 2.0–2.9 mm. total length were presumed to have escaped through the net meshes, while larvae longer than 5 mm. may have escaped by dodging.

No significant relations were found between the numbers of adult yellowfin and skipjack and their respective larvae.

STIMATES OF LARVAL TUNA ABUNDANCE IN THE CENTRAL PACIFIC

By Donald W. Strasburg, *Fishery Research Biologist*,
Bureau of Commercial Fisheries

or the past several years the Pacific Oceanic hery Investigations (POFI), of the U. S. Fish Wildlife Service, has sampled adult tuna ks as a means of evaluating the tuna resources the central Pacific Ocean. Deep-swimming as, such as large yellowfin (*Neothunnus mac- terus*), bigeye (*Parathunnus sibi*), and alba- (*Germo alalunga*), were taken by longlining, surface dwelling tunas, such as skipjack *tsuwonus pelamis*), and small yellowfin and core, have been captured by live-bait fishing, etting, and trolling. The catches obtained these methods were used as indices of the lability, distribution, and abundance of the , and the biological studies of adult fish con- uted information on reproductive cycles, food ts, growth rates, and other phenomena.

or some of the above operations, good fishing ilities could frequently be judged by the pres- of sea birds, knowledge of the circulation ures, water of a certain color or temperature, her factors, but in the absence of such guides, ng sites were more or less randomly selected. reas where sea birds were scarce or absent, as a large part of the open ocean, our knowl- of surface tuna abundance was scanty, thus ng the question of the reliability of the sev- guides. Another inadequacy of the sampling od was that running ripe fish were rarely ht, either because of their migration from ishing grounds, cessation of feeding during ning, or the breaking up of schools during eproductive period. There was little precise mation, therefore, on the time and place of ning except for the general trends evident gonadal studies.

was believed that a study of the eggs, larvae, juveniles of tuna would be of considerable filling certain gaps in our knowledge. The occurrence of eggs and larvae, as collected in plankton tows, should indicate the recent or continuing presence of adult fish independently of external indicators, and should prescribe the time and place of spawning with accuracy, depending on current drift and ontogenetic age. With reliable estimates of abundance, it should be possible to determine the numerical relations between adult tuna, their eggs, and larvae.

Before these major problems could be studied effectively it was necessary to consider the sampling methods employed. Among other things, it was requisite to know the reliability of a plankton tow as a method of capturing tuna eggs and larvae, and also to standardize the time and depth of tow so that meaningful comparisons could be made between samples. Because of its occasionally profound effect on the catch, it was desirable to understand the rudiments of larval tuna behavior. A study of these problems resulted in the present report, but because tuna eggs are not presently identifiable, its scope is limited to larval and juvenile forms. I should like to express my gratitude to Walter Matsumoto for his help in identifying tuna larvae, and to other POFI staff members who aided in collecting and processing the samples and in reviewing the manuscript.

METHODS

Collecting

All larvae reported upon were collected by plankton tows made from the POFI vessels *Hugh M. Smith* and *Charles H. Gilbert*. Three cruises were limited to the Hawaiian area, and 12 took place in the equatorial Pacific with some emphasis on the waters of French Oceania. Matsumoto (1958) has already presented data for 8 of these 15 cruises (*Hugh M. Smith* cruises 5, 6, 7, 8, 11, 14, 15, and 18). The operational areas of the remaining 7 cruises are shown in figure 1, and appendix tables 5 through 11 summarize catch and effort for each station.

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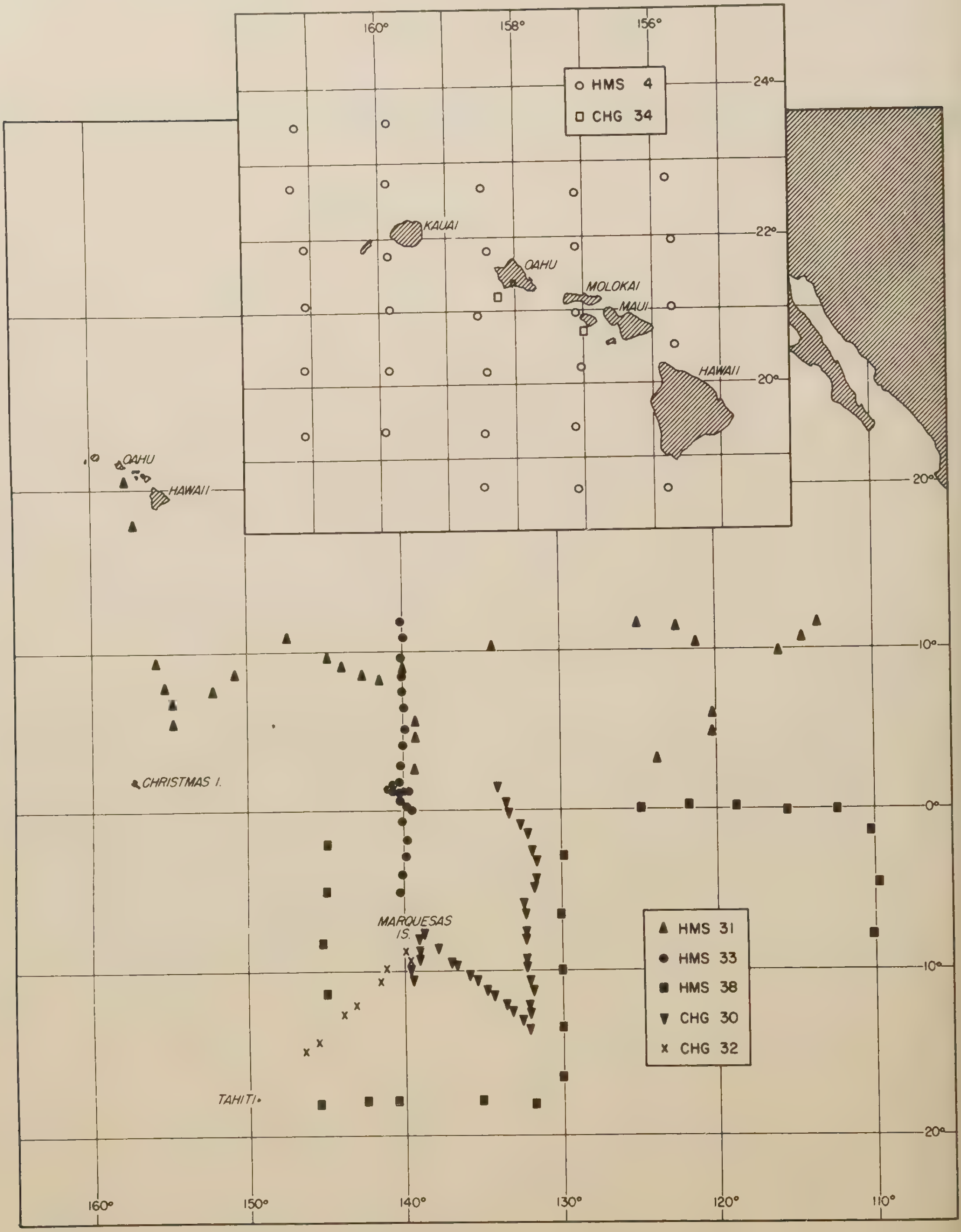

160°
158°
156°
24°
22°
20°
○ HMS 4
□ CHG 34
KAUAI
OAHU
MOLOKAI
MAUI
HAWAII
OAHU
HAWAII
CHRISTMAS I.
MARQUESAS IS.
TAHITI
▲ HMS 31
● HMS 33
■ HMS 38
▼ CHG 30
x CHG 32
20°
10°
0°
10°
20°
160°
150°
140°
130°
120°
110°

FIGURE 1.—Plankton stations sampled for larval tunas. HMS=*Hugh M. Smith*, CHG=*Charles H. Gilbert*.

ll plankton nets employed were 1 meter meter at the mouth and 5 meters in length. nets were of two types, open and closing, the ictural details of which are given by King and mond (1953) and King and others (1957). On ly cruises the nets were fabricated of Dufours ting silk or silk grit gauze (30XXX body and XX rear section), but these materials were r replaced by nylon (#656 Nitex body and 08 Nitex rear section); for all nets, mesh aper- s were 0.66 mm. in width in the body and mm. in the rear section and bag. The nets e equipped with flowmeters to measure the unt of water strained.

hree types of plankton tows were made: hori- al open net tows, oblique open net tows, and que closing net tows. For this study only e horizontal open net tows which fished at the ace were considered, and these can be termed ply surface or 0-meter tows. They fished just ly enough so that the nets did not break the ace. Oblique open net tows were made from surface to about 60 m. and from the surface bout 200 m.; for brevity these are designated -60 m. and 0–200 m. tows. The oblique clos- net tows involved a string of three nets, the er one being an open net fishing from the sur- to approximately 60 m., the middle a closing fishing from about 70 to 130 m., and the lower osing net fishing from about 140 to 200 m. se are designated as 0–60 m., 70–130 m., and 200 m. tows, with the first being indistin- hable from the 0–60 m. oblique open net tow. narily, tows were ½-hour in duration, but were as short as 15 minutes or as long as ur, at towing speeds of 2.5 to 3.5 knots.

ssing

the completion of each tow the nets were ed aboard, hosed down to remove plankton ues, and the samples transferred to glass jars and preserved in 10-percent borax- ralized formalin. As soon as possible after ning to the laboratory all fish and fish eggs removed, and, from these, all young tuna sorted and transferred to clean formalin for ge.

ification

rval tuna were identified principally with ence to Matsumoto's two recent papers (Matsumoto 1958 and 1959). POFI's extensive collections provided comparative material, and in some cases Matsumoto examined the specimens. The vast majority of specimens were referable to skipjack (*Katsuwonus pelamis*), yellowfin (*Neothunnus macropterus*), frigate mackerel (*Auxis thazard* and *Auxis* sp.), and little tunny (*Euthynnus yaito*); these are designated by their common names throughout the balance of this report. Of the unidentified material, a few specimens belonged to species for which the larvae are undetermined, and the remainder were severely mutilated.

Terminology

Larva denotes a specimen lacking the full complement of vertical fin spines and rays. This term includes most individuals below about 11 mm. in total length.

Length is total length, measured from the tip of the snout to the end of the longest caudal ray; where the caudal is forked, length is fork length.

Abundance is expressed as the number of larvae per thousand cubic meters of water strained, and also as the number of larvae beneath 10 square meters of sea surface.

Time is expressed in terms of the 24-hour clock, with zone time being used in each case.

Invertebrate plankton volume is the displacement volume measured subsequent to the removal of all fish, fish eggs, and organisms larger than 5 cm. longest dimension.

RELIABILITY OF A SINGLE SAMPLE

It was reasoned that if the catch made by one plankton net could be duplicated by another fishing at the same time and place, then plankton nets are reliable tools for sampling larval tuna within certain limitations of the sampling method. Reliability was first tested on *Charles H. Gilbert* cruise 30 to the Marquesas Islands. Two surface nets were launched simultaneously at 2000 hours each night; they fished about 20 feet apart for one-half hour after which they were retrieved, rinsed, the cod-ends replaced, and the procedure repeated for a second half-hour. Fourteen stations, each including a 4-haul series, were occupied, but the sampling was apparently done in the off-season (Aug.–Sept.) with respect to Marquesan tuna spawning, and few larvae were collected. A second test was made during January-March on *Hugh M. Smith* cruise 38 to French Oceania. Here, two half-hour tows were taken each night, one immediately following the other, so that members of a pair of samples differed slightly in time and space. The data obtained from these tests are listed in detail in th pendix and in summary form in table 1. respect to the latter, it should be noted tha species of tuna larvae were combined and only those stations were considered where l were taken by one or more nets.

TABLE 1.—*Numbers of larval tuna captured by paired night surface tows, with analyses of variance based on transforme*

$$\left[x' = \log\left(\frac{x+1}{10{,}000\text{m}^3}\right)\right]$$

Charles H. Gilbert cruise 30

Station No.	Position	Time: First ½ hr.	Time: Second ½ hr.
3	Port	3	1
	Starboard	1	2
7	Port	1	0
	Starboard	1	2
9	Port	1	0
	Starboard	0	0
13	Port	2	1
	Starboard	1	2
15	Port	0	0
	Starboard	1	0
17	Port	0	0
	Starboard	0	1
21	Port	14	13
	Starboard	17	26
23	Port	4	1
	Starboard	2	1
25	Port	0	0
	Starboard	2	0
32	Port	5	2
	Starboard	1	4

Analysis of variance

Source	Degrees of freedom	Sum of squares	Mean square
Time (T)	1	0.0185	0.0185
Stations (S)	9	4.5071	**0.5008
Positions (P)	1	0.0168	0.0168
T×S	9	0.1549	0.0172
T×P	1	0.1102	0.1102
S×P	9	0.2258	0.0251
T×S×P	9	0.2540	0.0282
Total	39	5.2873	

Hugh M. Smith cruise 38

Station No.	Time: First ½ hr.
23	9
45	2
47	11
49	0
54	4
57	7
59	13
64	2
66	3
75	2
79	16
82	56
85	10

Analysis of variance

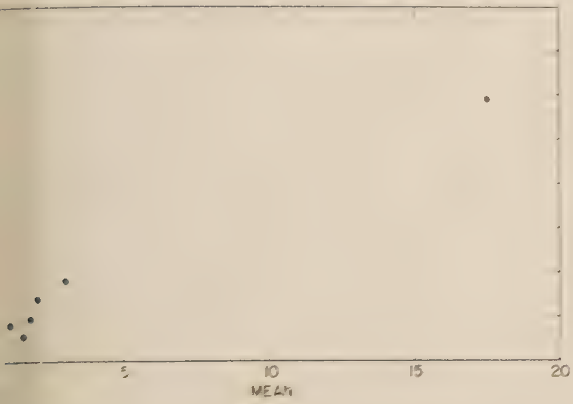
Source	Degrees of freedom	Sum of squares	Mean
Time	1	0.0023	
Stations	12	5.6160	
T×S	12	0.9542	
Total	25	6.5725	

**Indicates a significant F value ($p<0.01$).

A preliminary examination of the data indicated that they were skewed, and this was verified by plotting station variances against station means for the *Charles H. Gilbert* samples (fig. 2). A logarithmic transformation was accordingly performed, using the expression $x' = \log\left(\frac{x+1}{V}\right)$, where V is the volume of water strained in ten-thousand cubic meters. The use of the quantity $(x + 1)$ eliminated all zero terms. An analysis of variance was made on the transformed data (table 1). Interaction terms were assumed to be negligible, and were used to test significance.

The analysis of variance produced no signi *F*-values except for the "stations" category. cause the station interval varied from 90 t miles, significant differences are not surpr particularly in view of the extended geogra coverage of the two cruises (fig. 1). How between-station differences are of less interest are those types of variability leading to erro estimating spatial and temporal abundance.

It is difficult to conceive of a biological tion leading to statistically different port starboard catches, for any such differences



ʀᴇ 2.—Unadjusted larval tuna catches showing rela-
n between means and variances. Data from surface
vs taken on *Charles H. Gilbert* cruise 30 (table 1),
atified by station.

to be canceled in random sampling. On an a
ri basis one could almost say that the statisti-
est was unwarranted, but before concluding
the catches of the two nets were duplicates
well to consider additional information avail-
from table 1. The fact that a logarithmic
-formation was necessary implies contagion,
other words, tuna larvae are not randomly
buted in the ocean. They apparently occur
tches, perhaps resulting from spotty spawn-
early attempts to school or form feeding
egations, or other factors. Under these cir-
tances a single measurement is not too re-
an estimate of larval abundance. It is pos-
to set fiducial limits to the catch listed in
1 by use of the error terms' mean squares,
being estimates of the population parameter,
Ninety-five percent (2σ) confidence limits
selected, and these were converted to ratios
of their antilogs. For the *Charles H. Gil-*
data, the 95-percent limits were 46 percent
X 1/2.17) and 217 percent (100 X 2.17), while
he *Hugh M. Smith* samples the limits were
d 366 percent. For one tow to differ signifi-
y from another, its catch would have to be
r less than about ½ (¼), or greater than
times the catch of the second tow.

statistical differences were found between
les taken a half-hour apart at night; the
t of a change in catch with the advance of
is discussed later in this report.

VARIATIONS IN THE DISTRIBUTION OF LARVAL TUNA

General Vertical Distribution

Wade (1951) and, more recently, Matsumoto (1958) have demonstrated marked differences in larval tuna abundance between day and night surface catches. Matsumoto suggested that these differences were caused by a vertical diurnal migration of tuna larvae, with the fish rising to the surface at night and descending to depths probably not greater than 50 meters during the day. In addition to vertical migration, this diurnal variation in the catch could also be produced by the larvae dodging the net. Larvae should be able to see an approaching plankton net more clearly during the day than at night.

In order to compare the relative importance of migration and dodging in larval tuna sampling, a study was made of the night and day catches of nets fishing at several depths. The data for all species of tuna larvae were pooled, and an average catch was calculated from all available samples (*Hugh M. Smith* cruises 4, 5, 6, 7, 8, 11, 14, 15, 18, 31, 33, and 38; *Charles H. Gilbert* cruises 30, 32, and 34). The data were derived principally from samples containing at least one tuna larva, as it was reasoned that the inclusion of zero catches would introduce another variable, namely the complete absence of larvae, as opposed to merely not catching them. Where more than one net was used at a station, all samples, including zero catches, were considered when any net caught a tuna larva. Histograms showing the average catch per thousand cubic meters of water strained are presented in figure 3.

Of the several tendencies apparent in figure 3 perhaps the most noteworthy is the over-all decline in catch with depth. About 75–80 percent of the larvae occurred between the surface and 60 m., about 20–25 percent between 70 and 130 m., and practically none below this depth (closing nets operating from 332–127 m., and from 812–355 m. failed to capture tuna larvae on *Hugh M. Smith* cruise 33). In the night hauls a marked decrease was evident between the surface, 0–60, 70–130, and 140–200 m. captures, with the catches of the 0–200 m. tows being midway in number between those from the surface and 140–200 m. In the day hauls, on the other hand, there was a slight increase in catch with depth between the

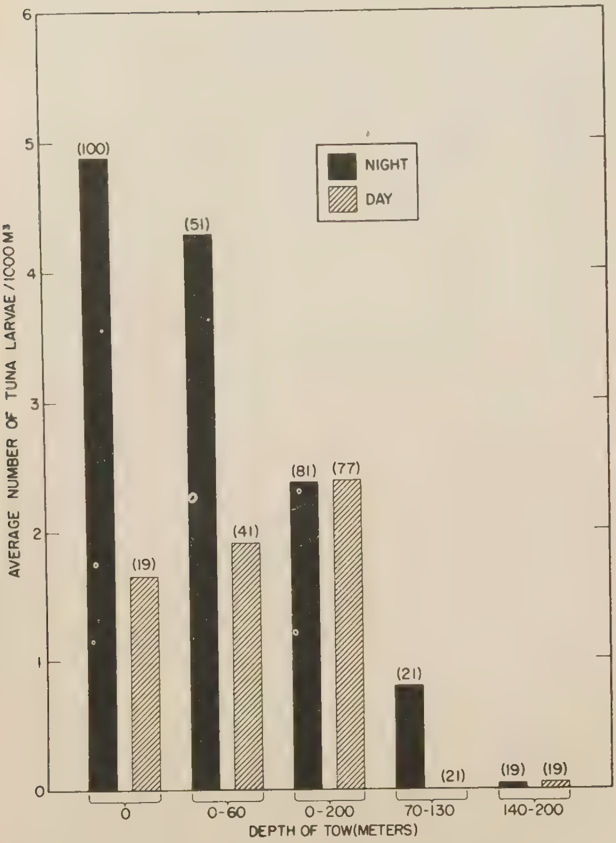


FIGURE 3.—Night and day variation in larval tuna catch with depth. Number of tows is shown in parentheses. The number of larvae obtained at each depth were as follows: 0 m.–927; 0–60 m.–432; 0–200 m.–592; 70–130 m.–20; and 140–200 m., 2.

surface, 0–60, and 0–200 m. tows. This illustrates an additional point as follows: the increase with depth may indicate a reduction in the amount of dodging with a decrease in illumination, or it may represent a downward migration during the daylight hours. This contrasts with the situation found for night catches where the density of larvae was much greater toward the surface. Such a change in abundance obviously signifies vertical migration, and, although dodging is a factor, we believe that migration is of greater importance in determining the number of larvae captured at a given depth and time.

Another tendency shown in figure 3 is the night-day difference in catch at various depths. This difference is most marked in the surface tows, less between 0 and 60 m., of dubious status at 70–130 m. because of the small numbers involved, and apparently lacking at 140–200 m. The average catch of the 0–200 m. tows (which encompas this entire range) showed no night-day differe The fact that the night-day ratio decreased w depth cannot be used to evaluate the separ effects of vertical migration and net-dodging, it is of interest here chiefly because of its bear on sampling vagaries. Shallow tows (0 or 0 m.) caught about half as many tuna larvae d ing the day as at night, whereas 0–200 m. t caught the same number during each peri Deep closing-net tows (70–130 and 140–200 showed little or no night-day differences, but th catches were too small for good comparisons.

In comparing the catches made at differ towing depths the question arises as to whet larval tuna are at times restricted to the up layers by temperature. Some evidence that t are restricted in this manner is given in figur where the temperatures at various depths plotted against closing net catches from th depths (sampling was completely stratified time and space). Here the larvae can be seen abound in the warm surface layers, and all c tures at 70–130 m. were made where the wa was 60°F. or warmer. One of the two lar taken at 140–200 m. was captured at a sta where a tongue of 60°F. water projected down into this depth range, but no explana

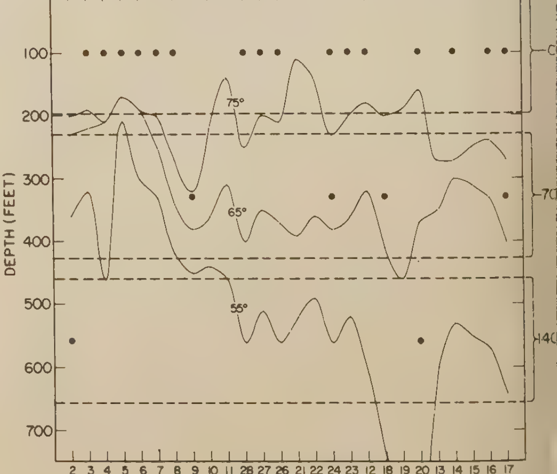


FIGURE 4.—Isotherm depths at plankton stations, *Hug Smith* cruise 33. Stations are ranked from nort south; temperature and depth measurements de from bathythermograph traces. Dots represent cl net tows yielding tuna larvae.

offered for the larva taken in 52–55°F. water
ween 140 and 200 m. Aside from this one in-
nce, it appears that 60°F. is the minimum tem-
ature at which tuna larvae occur.

LE 2.—*Correlation between larval tuna catches made*
0 meter, 0–60 m., and 0–200 m. tows on Hugh M.
nith *cruise 38*

[Analyses performed on data transformed by $x' = \log\left(\frac{x+1}{10{,}000\ \text{m}^3\ \text{of water strained}}\right)$]

Comparison between—	Number of stations considered	Calculated r-value
0 m. and 0–200 meters	12	−0.03
d 0 m. and 0–200 meters	13	0.10
0 m. and 0–60 meters	14	**0.67
d 0 m. and 0–60 meters	14	*0.60
neters and 0–200 meters	14	0.22

licates a significant r-value ($p<0.05$).
dicates a highly significant r-value ($p<0.01$).

he above data on vertical distribution and
t-day variations are of aid in selecting sam-
g times and depths, but the basic reason for
pling larval tuna is to obtain estimates of their
ndance. In order for these estimates to be
ningful it is requisite that they reflect the
ence of all tuna larvae, or, in other words, one
ld be able to say that there are x larvae be-
h y areal units of sea surface. If a plankton
samples all of the larvae beneath a given sur-
area then its catch provides an estimate of
lute abundance. If the tow captures a fixed
entage of the larvae, then an abundance esti-
can be made providing a conversion factor
vailable. Obviously a tow which catches no
portion of the larvae is useless in furnishing a
ble abundance estimate. With these points
nind it is well to consider the utility of the
rmation afforded by the various plankton
discussed above.

has already been shown that larval tuna
r from the surface to depths of 140 to 200 m.
he several tows considered, the 0–200 m. is
only one sampling this entire distribution, so
its catch is the best reference for comparative
oses. On cruise 38 of the *Hugh M. Smith*,
and 0–200 m. tows were taken simultaneously
m the same towing cable) each night, and
were followed by two successive one-half
surface tows. Although these tows differed
tly from each other with respect to time and
e they are the best available for the compari-
and correlation methods were used to determine the proportionality of their catches. The correlation analyses are summarized in table 2, where all species of tuna larvae were pooled and stations were disregarded if neither net captured a larval tuna. As in the analysis of reliability, the data were heteroscedastic, and a transformation in the form $x' = \log\left(\frac{x+1}{10{,}000\ \text{m}^3\ \text{water strained}}\right)$ was necessary.

The data in table 2 show that neither the surface nor the 0–60 m. tow captured a fixed fraction of the 0–200 m. catch. There were significant correlations between the surface and 0–60 m. captures, but these are of little importance because neither net sampled the entire vertical distribution of the fish. In the 0–60 m. and 0–200 m. tows, at least, the deep net sampled depths fished more extensively by the shallower net, and one would accordingly expect a "part-whole" correlation between their catches.

Figure 5 shows the tracks and catches of 0–60 and 0–200 m. tows at two stations where these nets were used simultaneously; at one station the catches were equal, at the other they differed considerably. Fishing depths were calculated from observed wire-angles, and thermocline depths from bathythermograph records. The dashed intercept lines of figure 5 delimit the time intervals in which the 0–200 m. tow fished in the

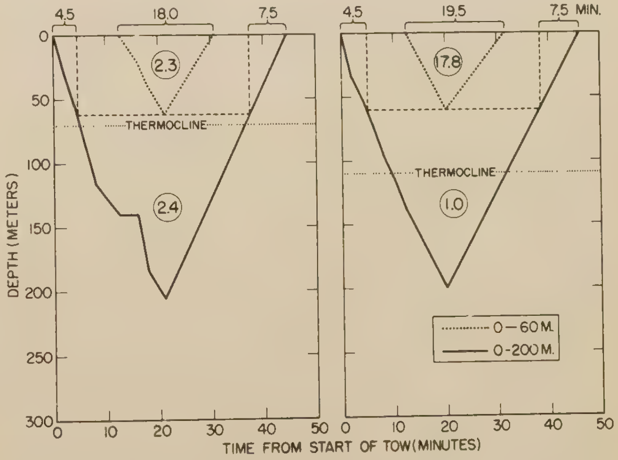


FIGURE 5.—Catch-depth-time relations for two stations where 0–60 m. and 0–200 m. tows were operated simultaneously at night (*Hugh M. Smith* cruise 38, stations 45 and 82). Left figure shows situation where catches were the same, right figure shows situation where catches were considerably different. Circled values represent catch (total tuna larvae per 1,000 cubic meters strained).

depth range of the 0–60 m. tow, these amounting to 12 minutes for each station. For the left panel of figure 5, the total 0–200 m. catch should be twelve-eighteenths of the 0–60 m. catch plus an additional catch, C_1, taken at depths greater than those fished by the 0–60 m. net. For the right panel, the comparable expression would be 12/19.5 X (0–60 m. catch) + C_2. Substituting the 0–60 m. catch values, these expressions reduce to 1.5 + C_1 and 11.0 + C_2 larvae/1000 cubic meters. The former is a reasonable approximation of the actual 0–200 m. catch of 2.4 larvae/1000 cubic meters, whereas the latter differs decidedly from the actual catch of 1.0 larvae. The majority of 12 other stations similarly analyzed also showed marked differences, suggesting that the disproportionality between the 0–60 m. and 0–200 m. catches may be caused by a spotty distribution of tuna larvae. Thermocline depth did not appear to be related to the catch, although there were indications of a catch decline when the 0–200 m. net fished deeper than the 60° isotherm.

In the preceding discussion the abundance of larval tuna was expressed in terms of the volume of water strained. The conversion of this measure to one based on areal units of sea surface was accomplished with the aid of the following conventions. It seemed obvious that only those tows fishing throughout the vertical range of tuna larvae could furnish accurate information on the number of larvae beneath a given surface area. Of the various tows studied, the 0–200 m. was the only one meeting this depth requirement, with a special situation existing for 3-level closing nets. Transformation of the 0–200 m. data involved multiplying the number of larvae per cubic meter strained by 200 (the depth of tow in meters) to give the number beneath 1 square meter of surface, and then multiplying this value by 10 to give the number beneath 10 square meters. (This area of sea surface was selected as a standard since it gave abundance estimates of about the same magnitude as the number of larvae captured per tow.) Multiplication by depth presupposed that sampling was equally intense at all depths, an assumption borne out by the relatively smooth tracks of the 0–200 m. nets shown in figure 5.

POFI's 3-level closing nets fished at depths of approximately 0–60, 70–130, and 140–200 m., so that essentially the entire 0–200 m. depth ra was sampled. The cumulative areal abunda estimate furnished by these 3 nets should ne equal that of a 0–200 m. net if a similar con sion were made. In this case, however, the de multiplier for each net was 60 (meters), and "surface" occurred at 0, 70, and 140 m., res tively.

Figure 6 depicts the 0–60, 70–130, 140–200, 0–200 m. data of figure 3 expressed as the num of larvae beneath 10 square meters of sea surf It is apparent from figure 6 that the sum of catches of the triple-net tows was less than 0–200 m. catch, particularly during the day. cause of the two 10 m. gaps in the triple r depth range one might expect about a 10-per differential (20/200) between the two catc Because the inequality was 36 percent for night hauls and 76 percent for the day hau

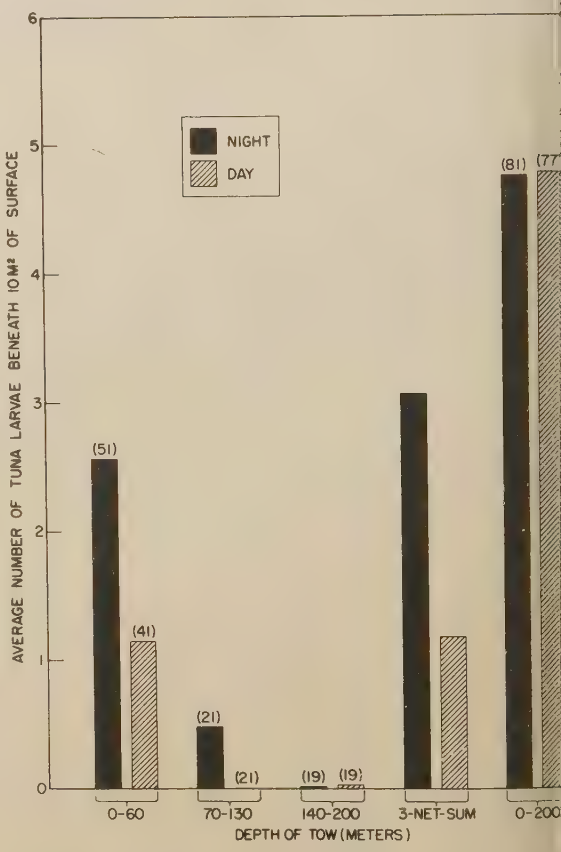


FIGURE 6.—Night-day variation in larval tuna catch depth, expressed in terms of areal catch. Numb tows is shown in parentheses. The number of l obtained at each depth was as follows: 0-60 m. 70-130 m.-20; 140-200 m.-2; and 0-200 m.-592.

or sampling stratification is suggested. The ne calculations made for the stations where 200 m. and triple-net tows were made together *lugh M. Smith* cruise 33, stations 18, 20, 26, d 28) produced a similar disparity (1.78 lar- e/10m² for night 0–200 m. tows, and 0.91 vae/10m² for night triple-net tows). How ich of this is sampling artifact and how much real can only be determined with more data. It would appear that, of the various hauls em- yed, the 0–200 m. tow, by sampling the com- te vertical range of larval tuna, produced the st useful information on their abundance. In lition, night-day catch variations were sup- ssed in this tow, although this might not be e in regions where a limiting isotherm, such 30°, lies deeper than 200 m. Disadvantages of 0–200 m. tow are that it may fish too deeply l its catch consists of relatively small numbers of tuna larvae (large numbers are frequently needed for statistical or other reasons). In an attempt to obtain a more representative sample of larval tuna POFI is presently testing a 0–140 m. oblique open-net tow. It is believed that the 0–140 m. sampling range covers the vertical distribution of tuna larvae, that day-night variations in catch will be small or absent, and that the number of captures can be increased by taking two half-hour samples per station. Where the major sampling goal is the capture of large numbers of larvae, then shallow tows at night are a better choice. In table 3, which shows the frequency of occurrence of catches of different magnitude by the several types of tow, it is apparent that our largest catches were obtained at night in surface or 0–60 m. tows. The noticeable species differences in day-night catch are discussed in the following section.

TABLE 3.—*Frequency of occurrence of catches of different magnitude in various types of tows*

ecies and where caught	When caught	Number of larvae/1000m³ strained										
		0.1 to 3.9	4.0 to 7.9	8.0 to 11.9	12.0 to 15.9	16.0 to 19.9	20.0 to 29.9	30.0 to 39.9	40 to 59	60 to 99	100 to 199	500 to 1,000
SKIPJACK												
ce	Day	2	1									
	Night	40	9	6	3		1	2				
n	Day	15	1									
	Night	22	7	2					1			
m	Day	44	4			1						
	Night	45	6	1	1							
m	Day											
	Night	5										
0 m	Day											
	Night	1										
YELLOWFIN												
e	Day	5	1									
	Night	48	8	3	2		1	1				
n	Day	19										
	Night	22	7	1	1		1					
n	Day	34	2									
	Night	44	1									
m	Day											
	Night	3										
m	Day											
	Night											
FRIGATE MACKEREL												
	Day											
	Night	17		1			1	1	2	2	3	1
	Day	8										
	Night	6	3	1			2	2		1	1	
n	Day	2										
	Night	4										
m	Day											
	Night											
m	Day	1										
	Night											

nal Variation in Shallow-Tow Catches

nsidering diurnal fluctuations in abundance, e (1951) found skipjack in 17 percent of his t surface samples but in only 3.6 percent of lay surface samples. He found a similar tion for what he termed *Euthynnus yaito* (little tunny), which was in reality frigate mackerel (Matsumoto, personal communication), but not for yellowfin. For the latter species, day and night tows were equally successful in capturing larvae, and high catches occurred randomly throughout a 24-hour period. Matsumoto (1958) noted a striking day and night disparity in the catch of "tuna larvae" (three species plus an unidentified category, combined) taken by surface tow, but any differences between skipjack and frigate mackerel, on the one hand, and yellowfin, on the other, were masked by his pooling of species. Actually his data (see below) included nearly 50 percent more skipjack and frigate mackerel, combined, than yellowfin.

The catch of tuna larvae at various times of day and at two sampling depths is shown in figure 7. Included are Matsumoto's data from *Hugh M. Smith* cruise 6, excluding his unidentified category. It is obvious that skipjack and frigate mackerel were infrequently captured at the surface during the day but were often taken there in numbers at night. Yellowfin were ir-

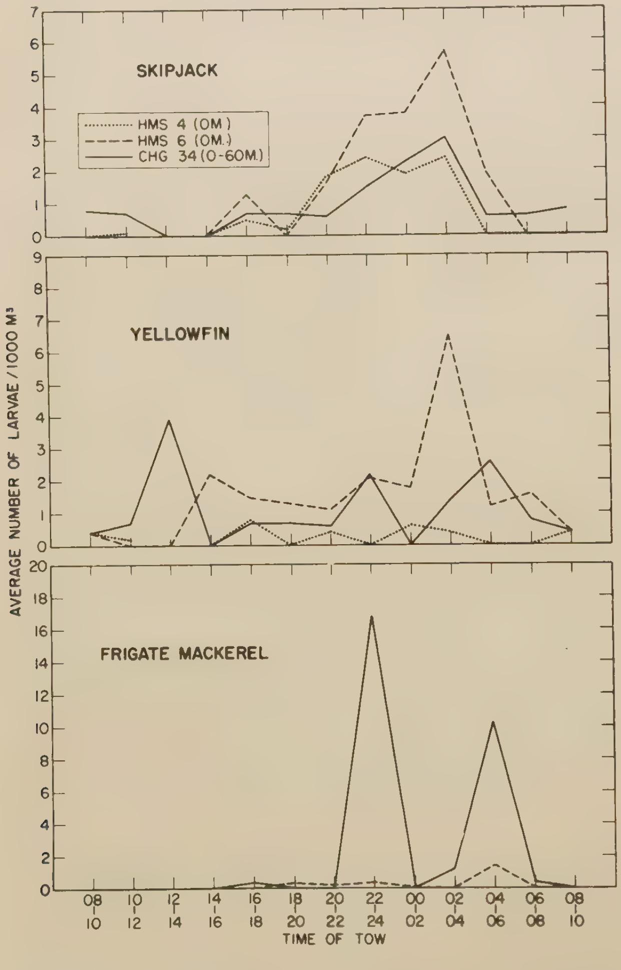


FIGURE 7.—Larval tuna catch by surface and 0–60 m. tows at various times of day. All data are from Hawaiian waters.

regularly distributed throughout a 24-hour pe
with low surface catches occurring chiefly
mid-morning. Skipjack showed about the
diurnal distribution in the 0–60 m. catches
the surface captures, whereas the 0–60 m. fri
mackerel captures were much greater than at
surface. The 0–60 m. yellowfin catch was irr
larly distributed and showed no clear relatio
the surface catch. This pattern of an increa
catch at night could be caused by either ver
migration or less successful dodging as discu
previously. If dodging only were involved
would expect the catch to be essentially cons
during the hours of darkness. In the cas
skipjack this is manifestly not so, for the
increased markedly between 1800–2000 and 0
0400 hours, during which time illuminatio
mained the same. Vertical migration there
appears to be the major factor causing th
crease in surface catch at night.

Another point illustrated by figure 7 is
surface captures of yellowfin and skipjack
menced in the afternoon, with yellowfin ap
ing in the catch earlier than skipjack. Du
the period from 1800–2000 hours, however,
species were uncommon or lacking in the su
catches. This is the time of sunset, and it
marks the beginning of the ascent of the
scattering layer and of invertebrate plan
Subsequent to sunset, the larvae of both t
increased in the surface catches. In orde
investigate the effects of sunset on larval
abundance, 6 half-hour surface tows were t
off Oahu just before and after sunset on eac
two consecutive days. An EDO depth rec
was used to measure the depth of the va
scattering layers, but good traces were obta
by this instrument on only one night. The l
tuna and invertebrate plankton catches made
ing the two nights, along with the EDO t
obtained on one night, are shown in figure 8
should be pointed out that in the figure, the
ted times of capture for larval tuna and inv
brate plankton represent the midpoints of
half-hour towing intervals.

The larval tuna catches shown in figure 8
cate a late afternoon increase in surface
dance for yellowfin but not for skipjack.
invertebrate plankton volumes peaked just
sunset, and declined thereafter. The two

ttering layer traces obtained became insepara- e from each other and from the surface trace at out the time when plankton volumes were eatest and the larval tuna catch the least. It ems evident that the change in environmental nditions accompanying sunset had marked ef- t on the surface abundance of tuna larvae and vertebrate plankton, and on the position of the ep scattering layer. It is likely that these ms are themselves interrelated.

Some contemporary thought holds that euphau- ds and other crustacean plankters are the prin- al components of this layer (Boden 1950, ore 1950). Our data showing an increase in face plankton concurrent with the rise of the p scattering layer are in accord with this idea, hough copepods and other small crustacea were siderably more abundant than euphausiids in samples under consideration. Supposedly se plankters are phototaxic and migrate to intain position at a weak state of illumination, h their movement to the surface at twilight ng a response to fading light (Clarke and kus, 1956). Although this explanation ac- nts for the twilight peaking in surface plank- it does not explain the marked decline oc- ring shortly after sunset. This decline is real, it was found on two successive days in the sent study and has been noted several times E. L. Nakamura.[1]

he question now arises whether tuna larvae important constituents of the deep scattering er. The following lines of evidence indicate t they are not: the surface abundance of larval a was complementary to that of the deep tering layer of invertebrate plankton at sun- larval skipjack and yellowfin were commonly n at the surface during the afternoon, well ore the deep scattering layer arrived at the ace; and our deep closing net samples indi- d extremely scanty abundance of tuna larvae 140–200 m., so that it is unlikely that they ır at the 350–550 meter depths occupied by deep scattering layer prior to ascent.

tion of Larval Tuna to Invertebrate Plankton

was noted that larval tuna and invertebrate kton were complementary in abundance at ight, and it was deemed worthwhile to ex- ne this relation further. A plot of the larval tuna catch (skipjack and yellowfin combined) with the accompanying invertebrate plankton volumes is given in figure 9. The plankton data were obtained from the report of King and Hida (1954) (*Hugh M. Smith* cruises 4 and 6) and from unpublished information in the POFI files (*Hugh M. Smith* cruise 38 and *Charles H. Gilbert* cruises 30, 32, and 34). The dotted line in figure 9 was fitted by eye to enclose the maximal situations of abundance.

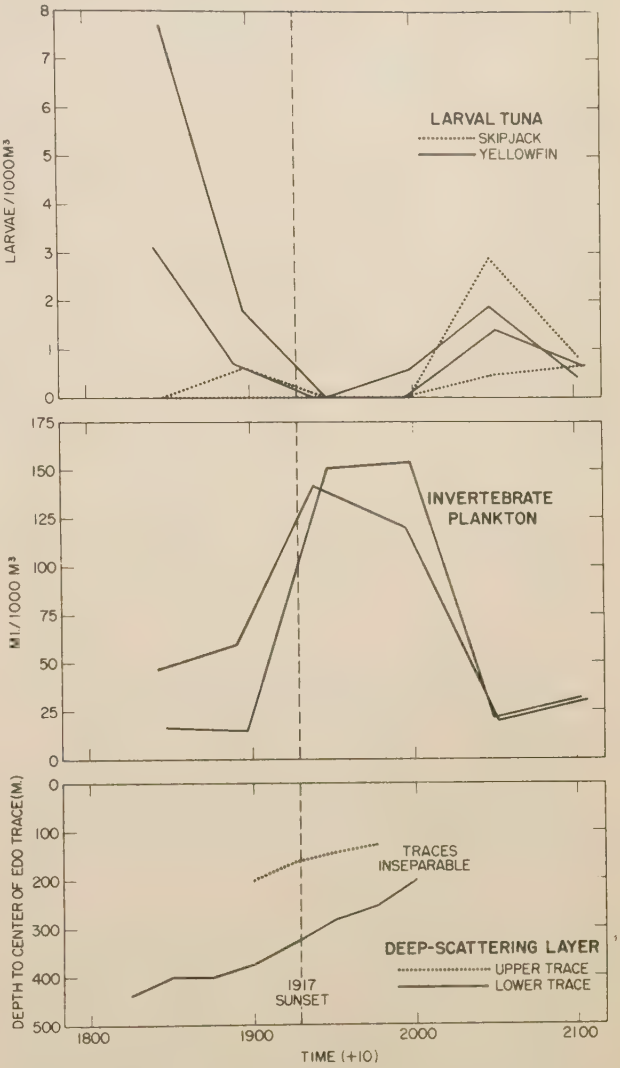


FIGURE 8.—Effect of sunset on larval tuna and invertebrate plankton catches, and depth of deep-scattering layer, as observed on *Charles H. Gilbert* cruise 34, stations 4 and 13, June 21–22, 1957. Plotted time for larval tuna and plankton catches is midpoint of towing interval.

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[1] Unpublished data in POFI files, Bureau of Commercial Fisheries Laboratory.

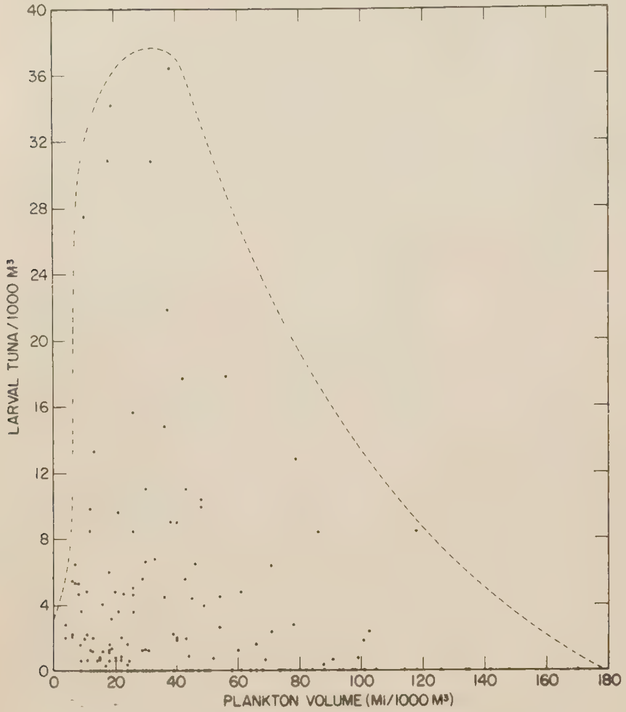

FIGURE 9.—Number of larval skipjack and yellowfin (combined) in relation to accompanying invertebrate plankton volumes. Data derived from 177 samples taken at 0 m. or 0–60 m. between evening and dawn. Curve fitted by eye to include maximal points.

In figure 9 it is seen that all of the large catches of tuna larvae were accompanied by small or moderate volumes of invertebrate plankton (roughly 10 to 60 ml./1000 cubic meters). The catches lowest in plankton contained few larvae, as did those richest in plankton. A similar but more marked situation obtained for frigate mackerel (not shown). It might be hypothesized that the low plankton concentrations were associated with either low-nutrient water or with enriched water so new to the euphotic zone that it had not been exploited biologically. In neither case would larval tuna be expected to abound. At the other extreme, large numbers of invertebrate plankters could represent both successful biological exploitation and a low level of grazing by higher forms. Many plankton feeders, such as small fish, squid, and crustaceans are of value to adult tuna as food (Reintjes and King, 1953; King and Ikehara, 1956), so that in their absence few adult tuna would be present, and logically there would be a paucity of tuna larvae (unless tuna spawn in areas of poor forage).

The shape and skewness of the dotted (fig. 9) were evident in the data segregated species and by cruise, and pooling was only c to emphasize the maximal (limiting?) situati The nearly vertical ascent of the left limb st in contrast to the gradual descent of the ri Whether the right-hand slope represents inve brates grazing on larval tuna is not known, there is some evidence that the left slope not depict tuna larvae feeding on invertebra Clemens (1956) found that juvenile tunas jected invertebrate plankters as food but av fed on softer-bodied larval fish, and the si larval tuna containing food, an 8 mm. skipj dissected by the writer had eaten a fish la one-third its length.

The apparent incompatability between la tuna and invertebrate plankton reminds one the exclusion hypothesis of Hardy (1935). the present investigation, it would seem m likely that the two groups of animals are show a differential response to some stimulus, such light intensity, rather than actively avoid each other.

Length Distribution of Larval Tuna by Depth and T

Knowledge of the relative abundance of var size groups is of considerable importance in problem of sampling larval tuna. It is desir to know the minimum size which can be captu by a given mesh, and the maximum size w can be taken at a certain towing speed. F the standpoint of tuna biology, relative size ab dance provides information on growth and m tality.

For this report, size was expressed in term length, and total length was selected from several length measurements used for fish (p. 2 Length was measured with the aid of a binoc dissecting microscope fitted with an ocular crometer. Measurements were made to the n est micrometer unit (0.095 mm.), and then verted to millimeters and tenths of millime Because of body distortion and frayed fins t measurements were sometimes overly precise, this has been remedied by grouping the fis 1-mm. length categories.

The percentage frequency of occurrence 1-mm. length groups of skipjack and yellowf shown in figure 10 for specimens collected *Hugh M. Smith* cruises 4, 6, 31, and 33,

arles H. Gilbert cruise 34. Larvae between
and 5.9 mm. dominated the catch of both
cies. Since tuna larvae are thought to measure
ween 2.4 and 3.0 mm. at hatching (Matsumoto
8) one would expect the 2.0–2.9 mm. category
predominate, and the fact that it did not do so
icates either an erroneous impression of hatch-
size, a different habitat for this group, or,
re likely, escapement through the net meshes.
se factors may also apply to the 3.0–3.9 mm.
up, for it was exceeded in number by the
4.9 mm. category in most instances. The nets
ployed in capturing these fish had aperture
ths of 0.66 mm. (body) and 0.31 mm. (rear
ion and bag). Large larvae (> 5 mm.) com-
ed only a small portion of the catch, and
ough this stems in part from their being
er in number, it also reflects their increased
ity and net-dodging powers.

lthough the surface, 0–60 and 70–130 m. tows
led similar length frequency distributions for
owfin they did not do so for skipjack. The
m. samples contained more large skipjack
ae than those from the surface, whereas the
30 m. collections had more small skipjack
ae than either shallow tow. In the case of the
30 m. data, however, the small sample size
s to discredit any conclusions drawn.

cause samples from deeper than 60 m. con-
d few tuna larvae of any kind, the discussion
e temporal aspects of length distribution is
ed to the surface and the 0–60 m. catches.
e were segregated into day and night hauls
eplotted as figure 11. Except for the yellow-
urface data the day samples contained few
and the slight contrasts may not be real. In
al terms there appeared to be little differ-
between the day and night length distribu-
of the surface catches, but in the 0–60 m.
the two species were more variable. Here
was a tendency for more large skipjack to
ken at night than during the day, whereas
llowfin the reverse was true. If these phe-
na are not sampling artifacts they may rep-
t behavior having to do with differential
al migration and net-dodging. Some evi-
points to the existence of different migra-
patterns between skipjack and yellowfin,
n figure 7 it was shown that yellowfin were
commonly caught at the surface during the
han skipjack. These captures could also

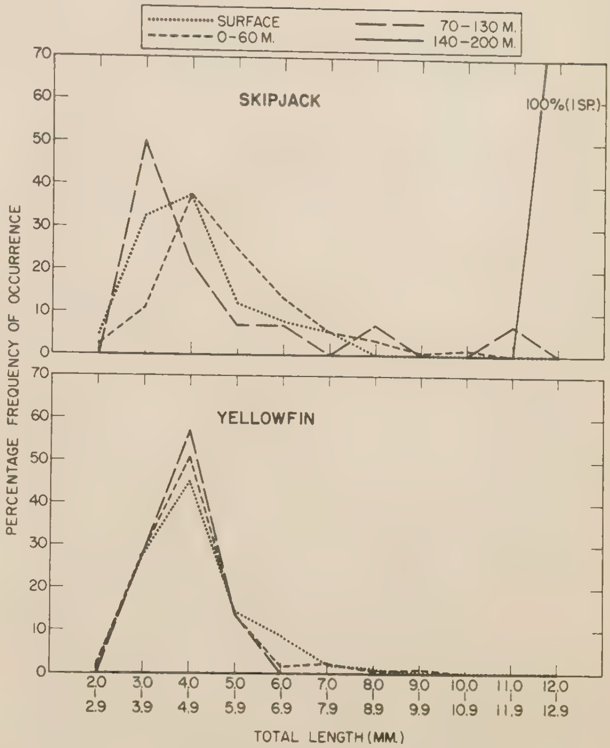

FIGURE 10.—Size variation of skipjack and yellowfin larvae in samples taken at various towing depths. Samples were collected at all times of day; percentages derived from the following catches: skipjack, 190 at 0 m.; 172 at 0–60 m.; 14 at 70–130 m.; and 1 at 140–200 m.; yellowfin, 311 at 0 m.; 183 at 0–60 m.; 7 at 70–130 m.; and 0 at 140–200 m.

have resulted from yellowfin being less adept at net-dodging, although this variable is difficult to assay.

Of the maximal sizes captured by surface tows, yellowfin were generally larger than skipjack (fig. 12); the difference in length between the yellowfin and skipjack larvae was fairly constant with various sampling times; and larger sizes of both species were taken with the advent of night. The last point indicates less successful dodging after dark, while the first two show that at a given time of day larger yellowfin than the skipjack can be captured, thus implying that yellowfin are slightly, but consistently, poorer dodgers. On the basis of casual observations of the adult swimming speeds, larval yellowfin may be slower swimmers than skipjack. The 0–60 m. data vary irregularly with sampling time but generally point out the diminishing effects of dodging as greater (darker) depths are sampled.

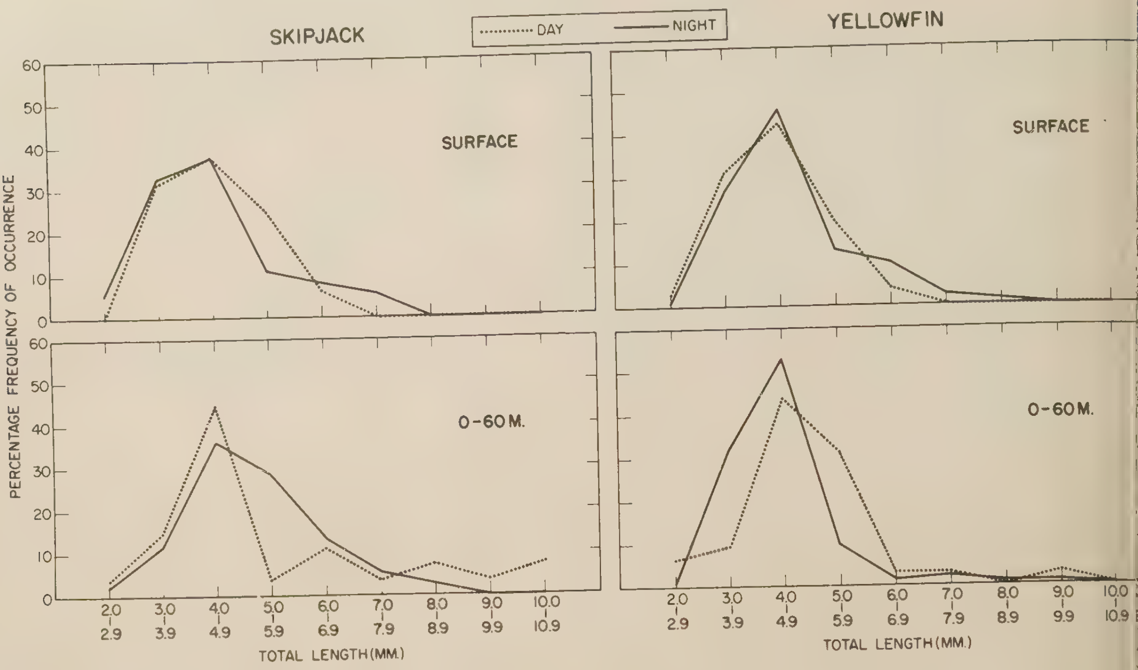

Figure 11.—Size variation of skipjack and yellowfin larvae in relation to time of sampling. Data derived following catches: surface tows (skipjack) 16 day, 174 night; (yellowfin) 71 day, 239 night; 0–60 m. tows (skip 27 day, 147 night; (yellowfin) 32 day, 144 night.

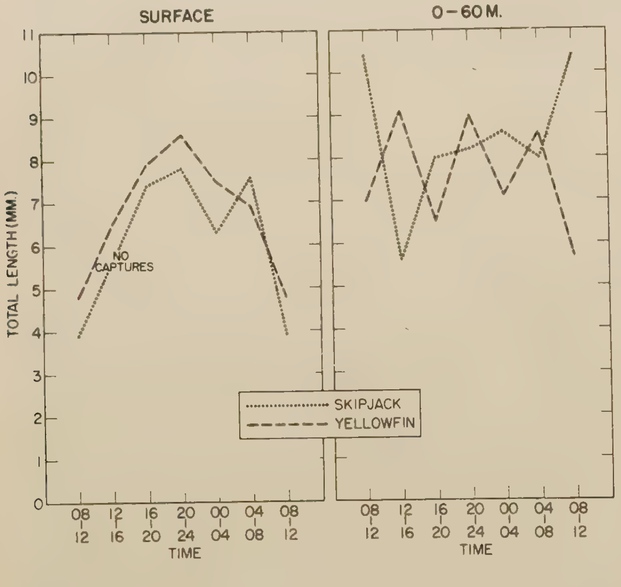

Figure 12.—Maximum length of tuna larvae captured at various times of day. Data derived from following catches: Surface tows, 190 skipjack and 311 yellowfin; 0–60 m. tows, 200 skipjack and 179 yellowfin.

ADULT VERSUS LARVAL TUNA ABUNDANCE

The determination of a numerical larval-adult tuna relation is of considerable practical value, for if a definite numerical relation could be es lished it might result in the substitution of pl ton nets for poles and longlines to provide mates of abundance in exploratory fishing. obvious limitation of this approach is that la contribute information only about the pres of spawning fish. In calculations of the la adult ratio particular attention must therefo paid to the size of the adults caught, for it w be pointless to correlate the presence of la and immature adults.

It was shown earlier that of the various p ton tows employed, the 0–200 m. tow was the one which sampled the entire vertical rang larval tuna. Where possible this sampling me has been used to provide estimates of larval a dance, with the catches being converted t number of larvae beneath 10 square mete sea surface, and the day and night samples considered of equal reliability.

Yellowfin are sexually mature in appre numbers only at lengths greater than 12 (Yuen and June, 1957); fish of this size are swimming and best sampled by longlining (phy and Shomura, 1953). For yellowfin, t fore, only longline captures were considered

se were expressed as catch per hundred hooks.
e data examined were taken from the reports
Murphy and Shomura (1953, 1955) dealing
th the catches made on cruises 5, 7, 11, and 18
the *Hugh M. Smith.* During these four cruises
gline stations were accompanied by a 0–200 m.
nkton tow on 55 occasions (see Matsumoto
8). At 13 of these stations both larval and
ult yellowfin were captured, at 25 stations only
ults were taken, at 3 stations only larvae were
tured, and at 14 stations neither larvae nor
ults were taken. Only the 13 stations yielding
h adults and larvae were analyzed, as it was
soned that the absence of larvae might connote
-spawning (the absence of adults in the pres-
e of larvae was infrequent and is not pres-
y explicable). The data examined are pre-
ed in table 4. As previously shown, the
al data are skewed, and as pointed out by
rphy and Elliott (1954), so are those for adult
owfin captured by longline. The data in table
ere made approximately normal by transform-
them logarithmically, and were analyzed by
relation methods which yielded a non-signifi-
r-value of 0.422 ($r_{.05}=0.553$, Snedecor
: 149). It would appear from this, that for
owfin either the larva/adult relation is not
defined, or that the individual catches are
reliable estimates of abundance.

E 4.—*Larval and adult yellowfin captured at the same station*

ugh M. Smith, cruise No.	Station	Larvae per 10 m²	Adults per 100 hooks
	2	1.5	3.2
	16	0.9	2.3
	24	1.3	3.4
	4	2.9	1.2
	6	1.4	0.8
	8	5.2	9.5
	9	4.1	5.0
	10	5.7	15.7
	11	8.2	10.3
	12	2.1	7.9
	22	4.6	29.3
	23	1.5	13.0
	4	3.2	0.4

nsiderable difficulty was experienced in re-
g the abundance of larval and adult skip-
The adults are essentially surface fish, so
it was necessary to derive abundance figures
the techniques peculiar to a live-bait fishery.
fishery provides two measures of abundance,
based on catch, the other on the number of
ls sighted during scouting. Adult-larval catch correlations could not be calculated because of a lack of plankton data, for in scouting, those observations attended by adequate plankton tows were generally secondary to other work programs. The available abundance estimates furnished by scouting thus suffer from inconsistency of effort and insufficient data on the number of fish comprising a school.

Despite these inadequacies there seemed to exist a rough relation between the numbers of larvae captured and schools seen, an example of which is shown in figure 13. The data used in this figure were derived from *Hugh M. Smith* cruises 33 and 38 (both primarily oceanographic) and *Charles H. Gilbert* cruise 32 (live-bait fishing). All three cruises investigated the waters of French Oceania and the central equatorial Pacific in January-March, the local skipjack season. For this study the region was divided into 13 areas (fig. 13) in accordance with the vessel tracks and certain oceanographic features. The number of hours of scouting and number of skipjack schools sighted were recorded by area, and from these figures a measure of abundance, expressed as the average number of skipjack schools sighted per 100 hours, was obtained. The data on adult abundance resulted from a total of 1,035 scouting hours in which 140 definitely identified skipjack schools were seen.

It would have been desirable to extract larval skipjack abundance figures from the captures made by 0–200 m. plankton tows, but unfortunately these tows were infrequent on the above cruises. As a consequence it was necessary to use the night catches of the 0 m. and 0–60 m. tows, both of which yielded about the same numbers of larval skipjack per station (see appendix tables 7, 8, and 10). As with the adult calculations, larval catch and effort were summarized by area, providing abundance estimates in terms of the average number of skipjack larvae per 1,000 cubic meters strained. The larval tuna data were based on a total of 406 skipjack larvae captured by straining 149,408 cubic meters of water.

The occurrence of larval skipjack coincided with that of adult schools, except for areas 6 and 11 (fig. 13). In addition, there was a general proportionality between the two variables, so that area 8 had large numbers of adults and larvae, the surrounding areas had small or moderate

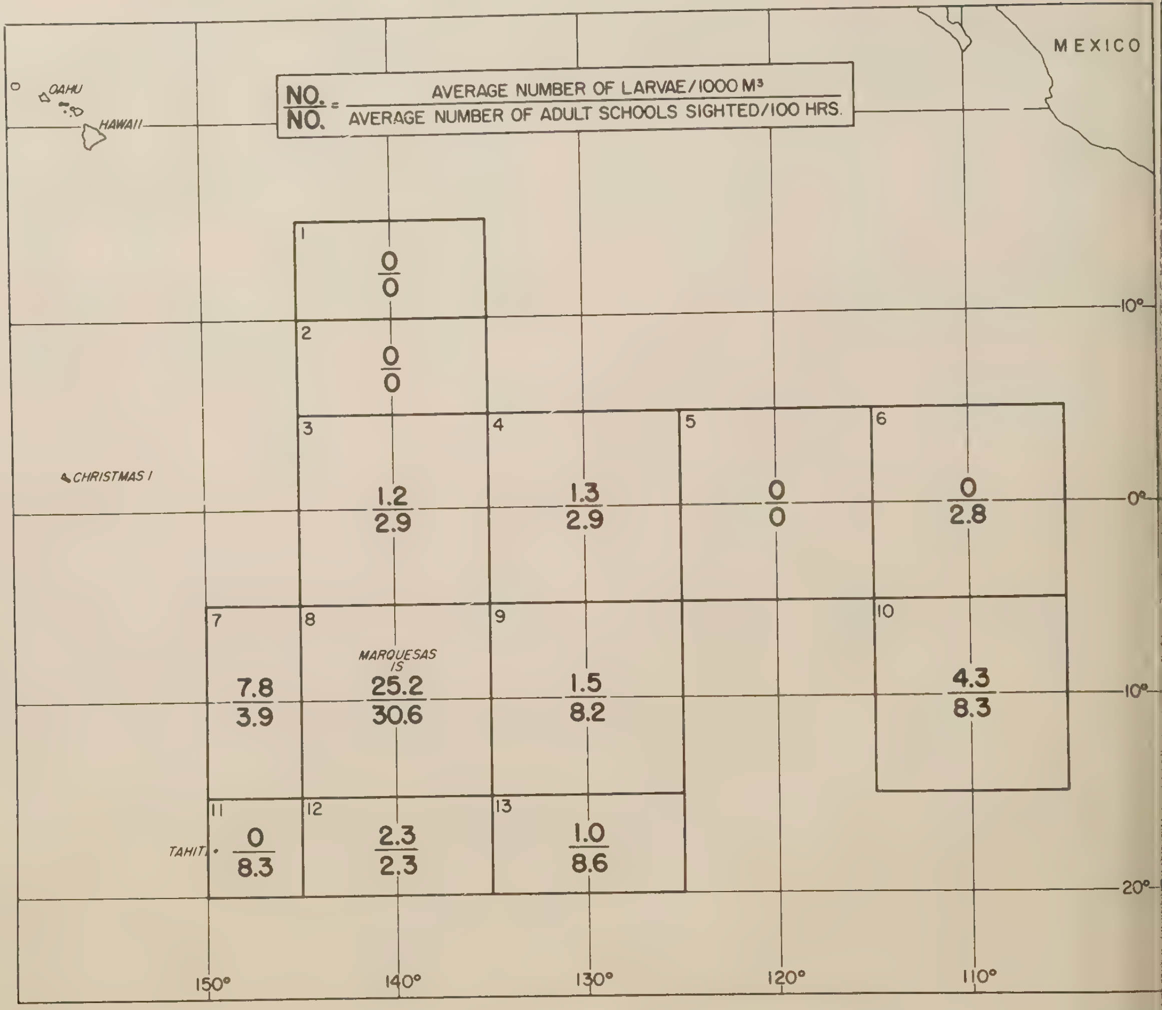
MEXICO
OAHU
HAWAII
NO. / NO. = AVERAGE NUMBER OF LARVAE/1000 M³ / AVERAGE NUMBER OF ADULT SCHOOLS SIGHTED/100 HRS.
1 0/0
2 0/0
3 1.2/2.9
4 1.3/2.9
5 0/0
6 0/2.8
CHRISTMAS I
7 7.8/3.9
8 MARQUESAS IS 25.2/30.6
9 1.5/8.2
10 4.3/8.3
11 TAHITI 0/8.3
12 2.3/2.3
13 1.0/8.6
10°
0°
10°
20°
150°
140°
130°
120°
110°

Figure 13.—Relation between numbers of larval and adult skipjack. Data from *Hugh M. Smith* cruises 33 and 3 *Charles H. Gilbert* cruise 32. See text for details.

numbers of each, and the peripheral areas frequently lacked both. As with yellowfin, the data were transformed logarithmically and analyzed by correlation methods. Ignoring the zero records, a non-significant r-value of 0.611 was obtained ($r_{.05} = 0.754$, Snedecor 1946: 149). Again it could not be determined whether the lack of correlation resulted from a real lack of inter-relation or merely reflected the inadequacy of the estimates.

SUMMARY

(1) As a prelude to the collection and interpretation of data on larval tuna abundance, it was considered necessary to know the reliability of the sampling methods, to standardize the and depth of sampling for comparative purp and to understand certain facies of larval behavior. This report deals with these prob by an analysis of the larval tuna catches mad 0, 0–60, 70–130, 140–200, and 0–200 m. plan tows. These tows were taken during 15 P cruises in the waters of the Hawaiian Isl the equatorial Pacific, and French Oceania

(2) The use of paired plankton nets sh that the catch made by a single net coul duplicated and was therefore reliable withi limitations of the sampling method.

(3) Most tuna larvae were captured bet the surface and 60 m. depth, with about percent of the catch between 70 and 130 m.

ctically none between 140 and 200 m. There
e marked night-day differences in catch at the
face but these became less as greater depths
e sampled, and were not present in the 0–200
catches. Diurnal catch differences were at-
uted to migration to the surface at night and
dodging the nets during the day, with the
mer being of greater importance to the catch.
ne evidence suggested that the 60°F. isotherm
be limiting to the occurrence of tuna larvae.

4) When larval tuna catches were referred to
l units of sea surface it appeared that the
0 m. plankton tow, by sampling the complete
ical distribution of the fish, produced the
t reliable abundance estimates. There was
apparent relation between the catch of this
and of shallower tows made at the same time.

) Catch data from 0 and 0–60 m. tows
ved that skipjack and frigate mackerel larvae
rarely captured during the day but were
mon at night. This tendency was less marked
yellowfin, particularly in the 0–60 m. tows.

) Both skipjack and yellowfin began to ap-
in the surface catch in the afternoon, but
tically none were caught near sunset. Their
orary disappearance was correlated with the
ing rise of the deep scattering layer and its
iated invertebrate plankton. Further study
ed an inverse relation between the numbers
rval tuna and invertebrate plankton volumes.
al tuna did not appear to be constituents of
leep scattering layer.

) Measurements of larval tuna demonstrated
the dominant length group in the catch was
4.0 to 4.9 mm. in total length. This size
predominated at each depth sampled, with
t non-modal shifts between day and night
between certain depths. Many larvae of the
.9 mm. group may have passed through the
eshes, as may some of the 3.0–3.9 mm. cate-
and fish larger than 5 mm. were not com-
Evidence derived from the larger larvae
ated that yellowfin were poorer dodgers than
ck.

No significant relation was found between
umber of yellowfin taken by longline and
umber of their larvae captured by 0–200 m.
ton tows. Similarly no significant relation
obtained between the number of skipjack
ls sighted per 100 hours scouting and the
er of larvae taken by 0 m. and 0–60 m. tows.

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APPENDIX

E 5.—*Larval tuna collected from surface hauls of one-hour duration on cruise 4 of the* Hugh M. Smith *in Hawaiian waters*

[All data except for larval tuna are from King and Hida, 1954; only skipjack and yellowfin larvae considered]

ation No.	Position		Date	Time started	Water strained (m³)	Number of fish in sample		
	North latitude	West longitude				Skipjack	Yellowfin	Total
	23°31′	161°07′	5/16/50	0934	2, 255. 3	0	1	1
	22°40′	161°15′	5/16/50	1722	2, 604. 7	6	7	13
	21°52.5′	161°07′	5/17/50	0240	2, 504. 5	0	0	0
	21°06′	161°05.5′	5/17/50	0925	2, 699. 9	0	2	2
	20°14.5′	161°07.5′	5/17/50	1640	2, 124. 9	0	0	0
	19°23.8′	161°06.3′	5/18/50	0028	2, 231. 5	2	0	2
	19°25′	159°50′	5/18/50	1048	2, 271. 9	0	0	0
	20°14.5′	159°50′	5/18/50	1835	2, 967. 4	0	0	0
	21°05′	159°50′	5/19/50	0255	2, 472. 3	5	4	9
	21°47.7′	159°51′	5/19/50	1000	2, 585. 2	1	1	2
	22°40′	159°50′	5/15/50	1456	2, 742. 2	0	0	0
	23°30′	159°50′	5/15/50	2316	2, 704. 2	12	0	12
	22°40′	158°30′	5/15/50	0503	2, 642. 3	0	0	0
	21°51′	158°29′	5/21/50	0150	2, 906. 2	16	0	16
	20°58′	158°26′	5/21/50	1005	2, 265. 3	0	0	0
	20°12.3′	158°30′	5/21/50	1610	2, 950. 2	0	0	0
	19°22′	158°28′	5/21/50	2253	3, 017. 4	2	0	2
	18°32.5′	158°27.8′	5/22/50	0546	2, 594. 0	0	0	0
	18°32′	157°05′	5/22/50	1531	2, 768. 9	0	2	2
	19°24.3′	157°10′	5/23/50	0018	3, 097. 3	0	0	0
	20°14′	157°03.5′	5/23/50	0911	3, 346. 3	0	1	1
	20°58.7′	157°10.2′	5/23/50	1648	2, 739. 9	0	1	1
	21°53′	157°08.5′	5/24/50	0120	2, 705. 6	13	5	18
	22°40′	157°10′	5/14/50	1852	2, 191. 5	2	0	2
	22°45′	155°49′	5/14/50	0820	1, 254. 7	0	0	0
	21°54′	155°48.2′	5/24/50	1333	2, 644. 7	0	0	0
	21°02.5′	155°45.5′	5/24/50	2107	2, 815. 1	5	1	6
	20°30′	155°45′	5/25/50	0214	3, 098. 8	5	0	5
	18°33.5′	155°48′	5/25/50	1740	3, 169. 4	0	0	0

6.—*Larval tuna collected by 3-level closing nets on cruise 31 of the* Hugh M. Smith *(numerous samples not processed)*

[All data, except larval counts, from King and others, 1957]

ion No.	Depth of tow (meters)	Position		Date 1955	Time started	Water strained (m³)	Number of fish in sample				
		Latitude	Longitude				Skipjack	Yellowfin	Frigate mackerel	Unidentified	Total
	0-41 [1]	20°38′ N	157°49′ W	9/23	1501(+10)	592. 9	0	1	0	0	1
	59-89 [1]					661. 8	0	0	0	0	0
	0-51 [1]	17°46′ N	157°09′ W	9/24	1418	686. 6	0	1	0	0	1
	56-110 [1]					458. 9	0	0	0	0	0
	0-92	12°02′ N	156°14′ W	9/26	0939	814. 1	0	0	0	0	0
	101-206					514. 8	0	0	0	0	0
	226-403					562. 1	0	0	0	0	0
	0-77	10°42′ N	156°04′ W	9/26	2222	1, 537. 0	0	0	0	3	3
	52-137					1, 083. 0	0	0	0	0	0
	0-63	09°24′ N	155°50′ W	9/27	1005	1, 113. 6	1	0	0	0	1
	61-127					921. 5	0	0	0	0	0
	137-240					1, 482. 9	0	0	0	0	0
	0-74	07°50′ N	155°16′ W	9/27	2309	1, 480. 7	2	4	0	0	6
	0-76	06°42′ N	154°54′ W	9/28	0948	1, 577. 7	1	0	2	0	3
	68-160					933. 7	0	0	0	0	0
	151-306					360. 4	0	0	0	0	0
	0-74	05°26′ N	154°52′ W	9/28	2215	1, 681. 7	1	0	0	0	1
	76-158					984. 4	2	3	0	0	5
	72-133	05°26′ N	154°22′ W	9/29	0933	508. 2	0	0	0	0	0
	0-60	06°30′ N	153°18′ W	9/29	2218	1, 542. 9	0	0	0	0	0
	0-63	07°30′ N	152°07′ W	9/30	0928	1, 298. 4	5	0	0	0	5

not reported by King et al. because of damage or malfunctioning of gear or other reasons. Most of these data not incorporated in present analysis.

TABLE 6.—*Larval tuna collected by 3-level closing nets on cruise 31 of the* Hugh M. Smith *(numerous samples processed)*—Continued

[All data, except larval counts, from King and others, 1957]

Station No.	Depth of tow (meters)	Position		Date 1955	Time started	Water strained (m³)	Number of fish in sample			
		Latitude	Longitude				Skipjack	Yellowfin	Frigate mackerel	Unidentified
15	66-132	08°26′ N	150°54′ W	9/30	2157	833.0	2	0	0	0
16	0-64	09°13′ N	149°48′ W	10/1	0932	1,285.6	0	0	0	0
	52-145					1,026.8	0	0	0	0
19	115-346	11°32′ N	148°13′ W	10/2	0845	1,008.5	0	0	0	0
21	0-59	10°55′ N	147°10′ W	10/2	2200	1,503.2	0	2	0	0
21	161-300					360.4	0	0	0	0
22	171-315	10°16′ N	146°08′ W	10/3	0929	851.8	0	0	0	0
24	0-68	09°40′ N	144°54′ W	10/3	2153	1,502.7	0	1	1	0
	141-259					1,197.1	0	0	0	0
25	0-75	09°02′ N	143°57′ W	10/4	0918	1,298.2	0	0	2	0
27	0-71	08°34′ N	142°34′ W	10/4	2201	1,502.2	0	2	0	1
	47-132					1,772.8	0	0	0	0
28	0-57	08°06′ N	141°24′ W	10/5	0923(+9)	1,500.9	0	4	0	0
	63-135					1,310.3	0	0	0	0
30	0-68	08°55′ N	140°02′ W	10/5	2155	1,349.1	3	2	0	2
	59-137					1,740.8	0	0	0	0
	131-259					1,408.7	0	0	0	0
33	80-129 [1]	10°29′ N	137°43′ W	10/6	2155	----------	0	0	0	0
34	90-128 [1]	11°16′ N	136°39′ W	10/7	0931	----------	0	0	0	0
	141-303					1,077.3	0	0	0	0
36	59-160	10°45′ N	135°36′ W	10/7	2152	335.7	0	0	0	0
37	0-79	10°10′ N	134°12′ W	10/8	0931	1,374.7	0	1	0	0
	61-152					1,019.6	0	0	0	0
42	66-143	09°31′ N	129°53′ W	10/9	2155	737.7	0	0	0	0
	147-279					1,195.7	0	0	0	0
43	80-170	10°03′ N	128°18′ W	10/10	0938	521.0	0	0	0	0
	180-334					760.5	0	0	0	0
45	54-167	10°30′ N	127°16′ W	10/10	2156(+8)	825.4	0	0	0	0
46	184-305	10°55′ N	126°12′ W	10/11	0937	404.4	0	0	0	0
48	0-60	11°36′ N	125°00′ W	10/11	2142	1,201.7	0	0	2	0
	61-143					545.2	0	0	0	0
49	0-68	12°11′ N	123°48′ W	10/12	0933	1,426.4	0	0	0	0
	66-141					882.6	0	0	0	0
	147-256					916.6	0	0	0	0
51	0-41	11°20′ N	122°28′ W	10/12	2137	1,432.6	0	0	6	0
	61-130					988.3	0	0	0	0
	137-276					882.2	0	0	0	0
52	0-59	10°19′ N	121°13′ W	10/13	0927	1,715.2	0	1	2	0
	137-300					648.2	0	0	0	0
54	0-61	09°26′ N	119°58′ W	10/13	2137	1,438.7	0	0	0	0
	66-152					972.5	0	0	0	0
55	61-140	08°38′ N	118°53′ W	10/14	0934	265.9	0	0	0	0
	137-259					934.4	0	0	0	0
57	137-257	09°14′ N	117°28′ W	10/14	2138	1,222.4	0	0	0	0
58	0-82	09°56′ N	115°55′ W	10/15	0930	1,547.1	0	0	1	0
	61-162					1,176.5	0	0	0	0
	137-302					717.4	0	0	0	0
60	0-43	10°40′ N	114°34′ W	10/15	2142	1,160.4	0	1	0	0
	161-263					581.7	0	0	0	0
61	0-43	11°30′ N	113°30′ W	10/16	0925	1,332.8	0	2	0	0
	68-121					959.8	0	0	0	0
	151-259					842.4	0	0	0	0
63	42-156	12°22′ N	112°27′ W	10/16	2138(+7)	1,283.9	0	0	0	0
	94-315					1,039.7	0	0	0	0
65	61-126	07°00′ N	108°37′ W	10/27	2151	1,039.2	0	0	0	0
68	0-48	04°34′ N	109°24′ W	10/28	2123	1,372.7	0	0	0	0
	161-245					943.5	0	0	0	0
69	0-43	03°10′ N	110°12′ W	10/29	1027	1,178.2	0	0	0	1
	74-126					967.6	0	0	0	0
	165-263					955.7	0	0	0	0
71	0-45	02°10′ N	110°54′ W	10/29	2320	1,347.6	0	0	0	4
74	76-135	00°14′ S	112°20′ W	10/30	2127	475.2	0	0	0	0
	171-277					586.4	0	0	0	0
75	0-48	01°23′ S	112°46′ W	10/31	0922(+8)	1,335.9	0	0	0	1
	54-122					413.6	0	0	0	0
83	0-47	07°42′ S	114°52′ W	11/2	2127	1,264.4	0	0	0	0
	56-120 [1]					92.8	0	0	0	0
85	157-276	07°56′ S	120°04′ W	11/4	0926	686.8	0	0	0	0
87	80-135	06°44′ S	119°59′ W	11/4	2144	554.5	0	0	0	0
88	66-124	05°16′ S	120°04′ W	11/5	1024	804.3	0	0	0	0
90	59-139	04°15′ S	120°00′ W	11/5	2138	1,198.9	0	0	0	0
	68-295					1,334.0	0	0	0	0
91	0-40	02°48′ S	120°06′ W	11/6	0925	1,410.1	0	0	0	0
	74-126					437.2	0	0	0	0
	165-269					720.7	0	0	0	0
93	145-204 [1]	01°35′ S	119°59′ W	11/6	2141	429.2	0	0	0	0
108	0-47	04°32′ N	119°49′ W	11/9	0920	1,055.2	1	0	0	0
	78-136					1,006.7	0	0	0	0
	175-284					205.9	0	0	0	0
110	0-47	05°49′ N	120°00′ W	11/9	2122	1,390.8	4	0	0	0
	76-136					833.7	0	0	0	0
	171-284					781.1	0	0	0	0
111	66-127	05°10′ N	121°20′ W	11/10	0920	715.7	0	0	0	0
	147-257					1,060.5	0	0	0	0

[1] Data not reported by King et al. because of damage or malfunctioning of gear or other reasons. Most of these data not incorporated in present

BLE 6.—*Larval tuna collected by 3-level closing nets on cruise 31 of the* Hugh M. Smith *(numerous samples not processed)*—Continued

[All data, except larval counts, from King and others, 1957]

Station No.	Depth of tow (meters)	Position		Date 1955	Time started	Water strained (m³)	Number of fish in sample				
		Latitude	Longitude				Skipjack	Yellowfin	Frigate mackerel	Unidentified	Total
	0-46	04°05′ N	122°31′ W	11/10	2124	1,365.4	0	0	0	0	0
	54-118					1,105.2	0	0	0	0	0
	0-46	03°01′ N	123°47′ W	11/11	0919	1,785.6	0	2	0	1	3
	102-124					155.3	0	0	0	0	0
	141-284	00°22′ N	127°08′ W	11/12	2137	697.8	0	0	0	0	0
	0-41 [1]	02°04′ S	130°48′ W	11/14	0947 (+9)	1,080.6	0	0	0	1	1
	165-262					884.1	0	0	0	0	0
	0-47	01°09′ S	131°42′ W	11/14	2130	1,552.6	0	0	0	1	1
	66-136					234.6	0	0	0	0	0
	147-284					955.9	0	0	0	0	0
	0-48	00°10′ N	133°10′ W	11/15	0921	1,590.3	0	0	0	0	0
	61-122					1,137.3	0	0	0	0	0
	140-187 [1]					1,539.3	0	0	0	0	0
	0-54	05°36′ N	139°12′ W	11/17	2230	1,192.9	1	1	0	0	2
	40-134					905.4	0	0	0	0	0
	89-269					494.2	0	0	0	0	0
	0-40	04°32′ N	139°11′ W	11/18	1010	1,357.3	0	1	0	0	1
	66-116					1,034.1	0	0	0	0	0
	147-256					960.3	0	0	0	0	0
	0-40	03°27′ N	139°11′ W	11/18	2128	1,502.7	0	0	0	1	1
	161-240					480.6	0	0	0	0	0
	0-45	02°27′ N	139°13′ W	11/19	0908	1,696.3	0	1	0	4	5
	70-130					716.3	0	0	0	0	0
	179-207 [1]					444.1	0	0	0	0	0
	0-49	01°14′ N	139°27′ W	11/19	2129	1,718.1	0	0	0	0	0
	54-143					469.7	0	0	0	0	0
	61-122	00°16′ N	140°12′ W	11/20	1005	38.0	0	0	0	0	0
	0-42	01°05′ S	140°00′ W	11/20	2130	1,465.9	0	0	0	0	0
	0-46	02°43′ S	139°46′ W	11/21	0906	1,340.0	0	0	0	0	0
	61-118					878.6	0	0	0	0	0
	137-237					824.6	0	0	0	0	0
	141-271	04°03′ S	139°42′ W	11/21	2117	621.5	0	0	0	0	0
	0-43	05°31′ S	139°54′ W	11/22	1008	1,339.8	0	0	0	0	0
	63-126					966.4	0	0	0	0	0
	141-268					761.9	0	0	0	0	0
	147-248	06°33′ S	139°26′ W	11/22	2128	987.9	0	0	0	0	0
	0-53	00°35′ N	157°47′ W	12/8	2121 (+10)	1,463.0	0	0	0	0	0

Data not reported by King et al. because of damage or malfunctioning of gear or other reasons. Most of these data not incorporated in present analysis.

TABLE 7.—*Larval tuna collected on* Hugh M. Smith *cruise 33 in equatorial waters*

tation No.	Approximate depth of tow (meters)	Position		Date 1956	Time started (+10)	Water strained (m³)	Number of fish in sample				
		Latitude	Longitude				Skipjack	Yellowfin	Frigate mackerel	Unidentified	Total
	0-60	11°54.9′ N	140°02′ W	3/9	1019	2,020	0	0	0	0	0
	70-130					924	0	0	0	0	0
	140-200					1,303	0	0	1	0	1
	0-60	10°52′ N	139°57′ W	3/9	2127	2,598	0	0	7	0	7
	70-130 [1]					1,547	0	0	8	0	8
	140-200 [1]					1,700	0	0	4	0	4
	0	10°51′ N	139°58′ W	3/9	2246	2,352	0	0	19	0	19
	0-60	09°35′ N	140°05′ W	3/10	0908	1,512	0	0	4	0	4
	70-130					1,171	0	0	0	0	0
	140-200					1,265	0	0	0	0	0
	0-60	08°36.5′ N	140°09′ W	3/10	2118	[2] 1,600	0	0	2	0	2
	70-130					1,295	0	0	0	0	0
	140-200					1,333	0	0	0	0	0
	0				2224	1,895	0	1	3	0	4
	0-60	07°22′ N	140°01′ W	3/11	0916	1,282	0	1	3	0	4
	70-130						0	0	0	0	0
	140-200					302	0	0	0	0	0
	0-60	06°28.5′ N	139°56′ W	3/11	2113	1,407	0	1	4	0	5
	70-130					1,206	0	0	0	0	0
	0				2225	1,974	0	0	6	0	6
	0-60	05°10′ N	139°51′ W	3/12	0917	1,283	0	1	0	0	1
	70-130					1,890	0	0	0	0	0
	140-200					1,247	0	0	0	0	0
	0-60	04°06′ N	140°00′ W	3/12	2200	2,342	0	0	0	0	0
	70-130					1,627	0	4	0	0	4
	140-200					202	0	0	0	0	0

footnotes at end of table.

TABLE 7.—*Larval tuna collected on* Hugh M. Smith *cruise 33 in equatorial waters*—Continued

Station No.	Approximate depth of tow (meters)	Position		Date 1956	Time started (+10)	Water strained (m³)	Number of fish in sample			
		Latitude	Longitude				Skipjack	Yellowfin	Frigate mackerel	Unidentified
10	0–60	02°45′ N	140°07′ W	3/13	0934	1,588	0	0	0	0
	70–130					945	0	0	0	0
	140–200					1,442	0	0	0	0
11	0–60	01°48′ N	140°13′ W	3/13	2117	1,316	0	0	0	0
	70–130					1,155	0	0	0	0
	140–200					1,354	0	0	0	0
	0				2228	1,953	0	0	0	0
12	0–60	00°29′ N	140°06′ W	3/14	0928	1,775	5	0	0	0
	70–130					103	0	0	0	0
	140–200					2,639	0	0	0	0
13	0–60	00°40′ S	140°07′ W	3/14	2115	1,435	0	0	0	0
	70–130					811	0	0	0	0
	140–200					2,175	0	0	0	0
	0				2219	2,356	0	0	1	0
14	0–60	01°58′ S	139°46′ W	3/15	0924	1,361	0	3	0	0
	70–130					1,540	0	0	0	0
	140–200					2,632	0	0	0	0
15	0–60	03°00′S	139°54′ W	3/15	2112	1,786	0	0	0	0
	70–130					1,062	0	0	0	0
	140–200					8	0	0	0	0
	0				2220	2,394	0	2	0	0
16	0–60	04°03′ S	140°07′ W	3/16	0848	1,848	1	4	0	0
	70–130					1,012	0	0	0	0
	140–200					756	0	0	0	0
17	0–60	05°03′ S	140°16′ W	3/16	1949	1. 583	64	5	4	0
	70–130					1,082	1	0	0	0
	140–200					628	0	0	0	0
	0				2059	2,663	39	5	1	0
18	0–60	00°11′ N	139°53′ W	3/18	2134	4,706	0	0	0	0
	70–130					2,364	4	0	0	1
	140–200					4,983	0	0	0	0
	0–200				2245	1,633	0	1	0	0
19	0–60	00°06′ N	139°37′ W	3/19	1041	1,753	0	0	0	0
	70–130					1,382	0	0	0	0
	140–200					2,598	0	0	0	0
20	0–60	00°00.6′ N	139°25.4′ W	3/19	2118	2,043	0	1	0	0
	70–130					1,618	0	0	0	0
	140–200					2,796	1	0	0	0
	0–200				2235	1,914	0	0	0	0
21	0–60	01°07′ N	140°07′ W	3/20	2125	2,375	0	0	0	0
	70–130					542	0	0	0	0
	140–200						0	0	0	0
	0–200				2238	2,519	0	0	0	0
22	0–60	01°06.4′ N	140°03.8′ W	3/21	0941	1,830	0	0	0	0
	70–130						0	0	0	0
	140–200					1,053	0	0	0	0
	332–127	01°05′ N	140°03′ W	3/21	1048	1,461	0	0	0	0
23	0–60	01°06′ N	140°05′ W	3/22	0924	2,114	1	0	0	0
	70–130					734	0	0	0	0
	140–200					1,185	0	0	0	0
	812–355				1030	1,353	0	0	0	0
24	0–60	01°06.2′ N	140°10′ W	3/22	2125	1,506	1	0	0	0
	70–130					1,731	3	0	0	0
	140–200					1,583	0	0	0	0
26	0–60	01°09.2′ N	140°30.4′ W	3/23	2121	1,946	0	3	0	0
	70–130					867	0	0	0	0
	140–200					1,073	0	0	0	0
	0				2314	2,934	1	0	1	0
	0–200				2239	2,487	3	0	0	0
27	0–60	01°11.7′ N	140°32.9′ W	3/24	1055	2,055	0	1	2	0
	70–130					1,049	0	0	0	0
	140–200					2,319	0	0	0	0
28	0–60	01°13.9′ N	140°35.4′ W	3/24	2122	2,558	3	0	0	0
	70–130					1,561	0	0	0	0
	140–200					624	0	0	0	0
	0–200				2234	1,874	2	1	0	0

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[1] Nets came in open.

[2] Estimated.

TABLE 8.—*Larval tuna collected on* Hugh M. Smith *cruise 38 in equatorial waters and near French Oceania*

tation No.	Approximate depth of tow (meters)	Position		Date 1957	Time started	Water strained (m³)	Number of fish in sample					
		Latitude	Longitude				Skipjack	Yellowfin	Frigate mackerel	Little tunny	Unidentified	Total
	0–200	00°02′N	124°56′W	1/22	2000(+8)	1,490	0	0	0	0	0	0
	0–60					619	0	0	0	0	0	0
	0	00°02′N	124°54′W		2042	1,939	0	0	0	0	0	0
	0				2110	1,892	0	0	0	0	0	0
	0–200	00°13′N	121°46′W	1/23	2000	1,697	0	0	0	0	0	0
	0–60					984	0	0	0	0	0	0
	0	00°12′N	121°44′W		2050	2,614	0	0	0	0	0	0
	0				2119	2,214	0	0	0	0	0	0
	0–200	00°13′N	118°49′W	1/24	2005(+7)	1,925	0	0	0	0	0	0
	0–60					913	0	0	0	0	0	0
	0	00°11′N	118°46′W		2050	2,168	0	0	0	0	0	0
	0				2117	2,101	0	0	0	0	0	0
	0–200	00°08′S	115°32′W	1/25	2000	2,975	0	0	0	0	0	0
	0–60					569	0	0	0	0	0	0
	0	00°06′S	115°30′W		2045	1,944	0	0	0	0	0	0
	0				2111	1,877	0	0	0	0	0	0
	0–200	00°01′S	112°14′W	1/26	2005	2,707	0	0	0	0	0	0
	0–60					615	0	0	0	0	0	0
	0	00°03′S	112°14′W		2050	1,772	0	0	0	0	0	0
	0				2116	1,829	0	0	0	0	0	0
	0–200	01°23′S	110°06′W	1/27	2000	1,893	0	0	0	0	0	0
	0–60					615	0	0	0	0	0	0
	0	01°23′S	110°04′W		2040	1,896	0	0	0	0	0	0
	0				2110	1,680	0	0	0	0	0	0
	0–200	04°43′S	109°45′W	1/28	2015	1,702	0	0	0	0	0	0
	0–60					849	0	0	0	0	0	0
	0	04°45′S	109°44′W		2055	1,578	0	0	0	0	0	0
	0				2121	1,518	0	0	0	0	0	0
	0–200	07°53′S	110°04′W	1/29	2005	2,370	3	0	0	0	0	3
	0–60					621	2	1	0	0	0	3
	0	07°55′S	110°02′W		2055	1,535	3	0	0	1	5	9
	0				2122	1,449	13	0	0	0	5	18
	0–200	02°58′S	129°55′W	2/25	2000(+9)	2,465	2	3	0	1	0	6
	0–60					860	2	0	0	0	0	2
	0	03°00′S	129°52′W		2100	1,814	1	0	0	0	1	2
	0				2128	1,723	0	0	0	0	0	0
	0–200	06°32′S	130°04′W	2/26	2120	2,277	3	1	0	0	0	4
	0–60					781	0	2	0	0	0	2
	0	06°33′S	130°01′W		2210	1,750	10	1	0	0	0	11
	0				2235	1,706	4	0	0	0	0	4
	0–200	10°00′S	130°00′W	2/27	2115	2,554	0	0	0	0	0	0
	0–60					767	3	0	0	0	0	3
	0	10°00′S	129°58′W		2200	1,601	0	0	0	0	0	0
	0				2225	1,592	1	1	0	0	0	2
	0–200	13°27′S	130°01′W	2/28	2130	2,726	0	0	0	0	0	0
	0–60					925	1	1	0	0	0	2
	0	13°30′S	130°00′W		2215	1,815	0	0	0	0	0	0
	0				2240	1,724	0	0	0	0	0	0
	0–200	16°30′S	130°04′W	3/1	2000	2,825	0	0	0	0	0	0
	0–60					884	3	1	0	0	0	4
	0	16°35′S	130°04′W		2050	1,473	0	4	0	0	0	4
	0				2115	1,481	0	1	0	0	0	1
	0–200	18°03′S	131°53′W	3/2	2040	2,026	0	1	0	0	0	1
	0–60					645	0	2	0	0	0	2
	0	18°01′S	131°54′W		2120	1,511	0	7	0	0	0	7
	0				2145	1,521	0	47	0	0	0	47
	0–200	17°50′S	135°06′W	3/3	2000	1,404	0	1	0	0	0	1
	0–60					462	3	0	0	0	1	4
	0	17°48′S	135°06′W		2035	1,180	8	5	0	0	0	13
	0				2100	1,188	6	15	0	0	0	21
	0–200	17°56′S	140°28′W	3/5	2030	1,967	1	1	0	0	0	2
	0–60					625	3	3	0	0	0	6
	0	17°55′S	140°25′W		2115	1,391	0	2	0	0	0	2
	0				2139	1,509	0	1	0	0	0	1
	0–200	17°55′S	142°28′W	3/6	2030(+10)	2,061	0	1	0	0	0	1
	0–60					1,022	0	2	0	0	0	2
	0	17°56′S	142°35′W		2115	1,570	0	3	0	0	0	3
	0				2140	1,622	1	0	0	0	0	1
	0–200	18°03′S	145°30′W	3/7	2000	2,184	0	0	0	0	0	0
	0–60					968	0	0	0	0	0	0
	0	18°02′S	145°31′W		2040	1,682	0	0	0	0	0	0
	0				2105	1,705	0	0	0	0	0	0
	0–200	11°18′S	145°02′W	3/15	2020	1,930	3	1	0	0	0	4
	0–60					557	0	1	0	0	0	1
	0	11°18′S	144°59′W		2105	1,515	0	2	0	0	0	2
	0				2130	1,209	0	2	0	0	0	2
	0–200	08°12′S	145°12′W	3/16	2020	2,478	2	1	0	0	0	3
	0–60					955	4	4	0	0	0	8
	0	08°09′S	145°12′W		2103	1,642	14	2	0	0	0	16
	0				2129	1,599	3	0	0	1	0	4
	0–200	05°00′S	145°00′W	3/17	2100	2,932	2	1	0	0	0	3
	0–60					1,010	10	8	0	0	0	18
	0	05°01′S	144°57′W		2147	1,785	54	1	1	0	0	56
	0				2212	1,678	60	1	0	0	0	61
	0–200	02°04′S	144°56′W	3/18	2020	2,327	3	2	0	0	0	5
	0–60					936	10	2	0	0	1	13
	0	02°06′S	144°54′W		2108	1,445	7	1	2	0	0	10
	0				2134	1,451	9	4	0	0	0	13

TABLE 9.—*Larval tuna collected on* Charles H. Gilbert *cruise 30 in French Oceania*

[All tows were at the surface and of a half-hour's duration]

Station No.	Position		Date 1956	Time started (+9)	Water strained (m^3)	Number of fish in sample				
	Latitude	Longitude				Skipjack	Yellowfin	Frigate mackerel	Little tunny	Unidentified
1	01°24.5′N	133°49′W	8/16	0959	1,804	0	0	0	0	0
2	00°24.5′N	133°09′W	8/17	0750	1,774	0	1	0	0	0
3	00°01′S	133°02′W		2000	1,570	0	1	0	0	0
					1,597	0	0	3	0	0
				2041	1,571	0	0	1	1	0
					1,533	0	0	1	0	0
4	00°54′S	132°22′W	8/18	0752	1,872	0	0	0	0	0
5	01°29′S	132°03′W		2003	1,572	0	0	0	0	0
					1,309	0	0	0	0	0
				2039	1,548	0	0	0	0	0
					1,555	0	0	0	0	0
6	02°44′S	131°42′W	8/19	0744	1,541	0	0	0	0	1
7	03°08′S	131°35′W		1959	1,562	0	0	0	0	1
					1,688	0	0	0	0	1
				2037	1,373	0	0	0	0	2
					1,320	0	0	0	0	0
8	04°25.5′S	131°39′W	8/20	0746	1,670	0	0	0	0	0
9	04°49′S	131°48.5′W		2000	1,567	0	0	0	0	0
					1,548	0	0	1	0	0
				2038	1,610	0	0	0	0	0
					1,597	0	0	0	0	0
10	06°01.5′S	132°17′W	8/21	0746	1,678	0	0	0	0	0
11	06°19.5′S	132°10′W		1958	1,409	0	0	0	0	0
					1,392	0	0	0	0	0
				2037	1,410	0	0	0	0	0
					1,413	0	0	0	0	0
12	07°32′S	132°05′W	8/22	0754	1,452	0	0	0	0	0
13	08°01.5′S	132°03′W		1957	1,775	1	0	0	0	0
					1,732	0	2	0	0	0
				2035	1,563	2	0	0	0	0
					1,552	1	0	0	0	0
14	09°22′S	132°09.5′W	8/23	0747	1,670	0	0	0	0	0
15	09°48′S	132°07′W		1954	1,672	0	1	0	0	0
					1,649	0	0	0	0	0
				2034	1,271	0	0	0	0	0
					1,249	0	0	0	0	0
16	10°51′S	132°00′W	8/24	0740	1,741	0	0	0	0	0
17	11°10′S	131°56′W		1957	1,705	0	0	0	0	0
					1,627	0	0	0	0	0
				2035	1,776	1	0	0	0	0
					1,726	0	0	0	0	0
18	12°12.5′S	132°05′W	8/25	0750	1,891	0	0	0	0	0
19	12°31′S	132°04′W		1956	1,843	2	0	0	2	0
				2033	1,755	0	0	0	0	0
						1	0	0	0	0
20	13°30′S	132°15.5′W	8/26	0749	1,697	0	0	0	0	0
21	13°02.5′S	132°31′W		2002	1,540	17	0	0	0	0
					1,533	13	0	0	0	1
				2040	1,687	25	0	0	0	1
					1,634	11	0	0	0	2
22	12°18′S	133°18′W	8/27	0749	1,418	0	0	0	0	1
23	12°02.5′S	133°33.5′W		2001	1,677	2	0	0	0	0
					1,561	2	0	0	0	2
				2040	1,615	1	0	0	0	0
					1,587	1	0	0	0	0
24	11°33′S	134°33′W	8/28	0742	1,706	0	0	0	0	0
25	11°09.5′S	134°45.5′W		2002	1,737	1	1	0	0	0
					1,646	0	0	0	0	0
				2040	1,545	0	0	0	0	0
					1,450	0	0	0	0	0
26	10°35′S	135°38.5′W	8/29	0800	1,706	0	0	0	0	0
27	10°17′S	135°52′W		1955	1,151	0	0	0	0	0
					1,107	0	0	0	0	0
				2033	1,322	0	0	0	0	0
					1,474	0	0	0	0	0
28	09°36.5′S	136°45′W	8/30	0801	1,562	0	0	0	0	0
29	09°21.5′S	137°01′W		2000	1,505	0	0	0	0	0
					1,462	0	0	0	0	0
				2038	1,306	0	0	0	0	0
					1,216	0	0	0	0	0
30	08°43′S	137°52′W	8/31	0802	1,747	0	0	0	0	0
31	07°32′S	138°54′W	9/1	0756	2,021	0	0	0	0	0
32	07°39′S	138°56′W		1957	1,682	1	0	0	0	0
					1,866	4	0	0	0	1
				2035	1,826	4	0	0	0	0
					1,521	2	0	0	0	0
33	08°50′S	139°08′W	9/2	0750	1,380	0	0	0	0	1
34	09°12′S	139°12′W		2005	1,457	1	0	0	0	0
					1,450	0	0	0	0	0
35	10°28′S	139°38′W	9/3	0754	1,188	0	0	0	0	0
36	10°00′S	139°41′W		1959	1,325	0	0	0	0	0
				2034	1,281	0	0	0	0	0

BLE 10.—*Larval tuna collected on* Charles H. Gilbert *cruise 32 in French Oceania; all tows were at the surface and of a half-hour's duration*

Station No.	Position		Date 1957	Time started (+10)	Water strained (m^3)	Number of fish in sample					
	Latitude	Longitude				Skipjack	Yellowfin	Frigate mackerel	Little tunny	Unidentified	Total
	14°57′ S	146°20′ W	2/19	1937	1, 490	36	15	0	2	0	53
	14°17.5′ S	145°31.5′ W	2/20	0347	1, 881	11	5	0	0	2	18
	12°48.5′ S	143°55′ W	2/20	1941	1, 834	0	1	0	0	0	1
	12°05′ S	143°06.5′ W	2/21	0346	1, 738	5	1	0	0	0	6
	10°39′ S	141°33′ W	2/21	1933	1, 760	4	4	0	0	0	8
	09°55.5′ S	141°03′ W	2/22	0345	1, 842	17	2	0	0	0	19
	09°22.5′ S	139°37′ W	2/27	1936	1, 467	6	0	0	0	0	6
	08°57′ S	139°54′ W	3/2	2121	1, 068	1	8	2	0	0	11

TABLE 11.—*Larval tuna collected on* Charles H. Gilbert *cruise 34 in Hawaiian waters*

[All tows were of a half-hour's duration]

tation No.	Approximate depth of tow (meters)	Position		Date 1957	Time started (+10)	Water strained (m^3)	Number of fish in sample					
		North latitude	West longitude				Skipjack	Yellowfin	Frigate mackerel	Little tunny	Unidentified	Total
	0–60	21°10′	158°19′	6/21	1240	1, 538	0	6	0	0	0	6
	0–60	21°09′	158°19′		1500	1, 189	0	0	0	0	0	0
	0–60	21°12.5′	158°21′		1742	1, 644	2	4	0	0	0	6
	0	21°11.5′	158°20.5′		1813	1, 282	0	4	0	0	0	4
	0	21°10.5′	158°20′		1840	1, 377	0	1	0	0	0	1
	0	21°10′	158°19.5′		1909	1, 504	0	0	0	0	0	0
	0	21°09′	158°19′		1942	2, 061	0	0	0	0	0	0
	0	21°10.5′	158°20′		2015	2, 156	1	3	0	0	0	4
	0	21°12′	158°20.5′		2049	1, 540	1	1	0	0	0	2
	0–60	21°11.5′	158°20′		2121	1, 616	0	0	0	0	0	0
	0–60	21°11′	158°19′	6/22	0013	1, 742	1	0	0	0	0	1
	0–60	21°11.5′	158°21′		0300	1, 681	1	0	0	0	0	1
	0–60	21°10′	158°19.5′		0622	1, 933	2	0	0	0	0	2
	0–60	21°10.8′	158°19.5′		0906	1, 719	3	0	0	0	0	3
	0–60	21°10′	158°18′		1154	1, 371	1	1	0	0	0	2
	0–60	21°12′	158°20.5′		1459	1, 663	0	0	0	0	0	0
	0–60	21°11.5′	158°19′		1743	1, 553	1	0	0	0	0	1
	0	21°11′	158°18.5′		1814	1, 426	0	11	0	0	0	11
	0	21°11′	158°17.5′		1844	1, 665	1	3	0	1	0	5
	0	21°10.5′	158°17′		1914	1, 593	0	0	0	0	0	0
	0	21°10.5′	158°16′		1945	1, 870	0	1	0	0	0	1
	0	21°11′	158°16.5′		2015	2, 060	6	4	0	0	1	11
	0	21°11.3′	158°18.4′		2045	2, 454	2	1	0	0	0	3
	0–60	21°11′	158°20.7′		2121	1, 616	2	2	0	0	0	4
	0–60	21°10.6′	158°19.5′	6/23	0001	1, 724	7	0	0	0	0	7
	0–60	21°11.3′	158°20.6′		0259	1, 485	4	1	0	0	0	5
	0–60	21°10′	158°20′		0603	1, 543	0	0	0	0	0	0
	0–60	21°10.5′	158°19.8′		0859	1, 412	0	2	0	0	0	2
	0–60	20°56′	157°50′		1652	1, 253	1	0	0	0	0	1
	0–60	21°10′	157°50′		1902	1, 412	1	1	0	0	1	3
	0–60	21°25′	157°21′		2305	1, 354	4	0	41	1	0	46
	0–60	21°37′	157°46.5′	6/24	0324	1, 618	5	0	8	0	0	13
	0–60	21°59′	157°45′		0621	1, 570	1	4	2	0	0	7
	0–60	22°20′	157°46′		0930	1, 645	1	0	0	0	0	1
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	0	20°43.8′	156°58′	7/11	1924	2, 496	0	4	77	0	0	81
	0	20°42.9′	156°56.5′		2059	2, 230	2	10	284	0	7	303
	0	20°42.1′	156°55.1′		2301	2, 400	0	5	140	0	1	146
	0	20°42.1′	156°55.1′		2337	2, 864	0	8	173	0	0	181
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	0	20°42.2′	156°55.6′		2233	2, 370	0	11	182	0	0	193
	0	20°42.1′	156°56.6′		2306	2, 295	4	59	234	0	0	297
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DONALD W. STRASBURG
and HEENY S. H. YUEN

PROGRESS IN OBSERVING TUNA UNDERWATER AT SEA

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Progress in Observing Tuna Underwater at Sea

By

Donald W. Strasburg and **Heeny S. H. Yuen**

Honolulu Biological Laboratory,
U.S. Bureau of Commercial Fisheries, Honolulu, Hawaii*

1. Introduction

The world's increasing demand for protein food makes it imperative that we improve the efficiency of harvest for those resources whose crops are not easily manipulated. In the central Pacific such a resource is oceanic skipjack, *Katsuwonus pelamis* (L.), a small surface-schooling tuna which is one of the most valuable seafoods in the area. Studies of larval skipjack (MATSUMOTO, 1958) and adults (IKEHARA, 1953; MURPHY and IKEHARA, 1955; WILSON and AUSTIN, 1959) indicate the species to be widespread and locally abundant, but in spite of this it is not exploited to the extent warranted by world demand. One factor limiting its capture is bait fish (TESTER, 1951; YAMASHITA, 1958), for most skipjack are caught by live-bait methods, and the bait species are usually delicate and in short supply. In the central Pacific these conditions restrict the fishery to waters adjacent to baiting grounds, and for these and other reasons the resource in large portions of the open ocean is untouched (SCHAEFER and REVELLE, 1959). A promising approach to the problems of increasing fishing efficiency, developing baitless techniques of capture, and exploiting new bait species is the understanding of skipjack behaviour as it is related to the fishing method. This subject, especially the equipment developed during our studies of it, forms the basis for the present report.

To obtain data on behaviour it was first necessary to devise a method of making underwater observations. A study of captive skipjack seemed to be precluded by earlier failures to maintain these fish in ponds and tanks (TESTER, 1952), and, in addition, it was desired to study their behaviour under fishing conditions. Placing an observer or a recording device beneath the surface from a fishing vessel was a logical solution to the problem.

2. Method of Fishing for Skipjack

An account of the present Hawaiian skipjack fishery has been given by JUNE (1951). Suffice it to say that commercial fishing is done from the sterns of 60–80 ft motor vessels from which skipjack schools are located by means of

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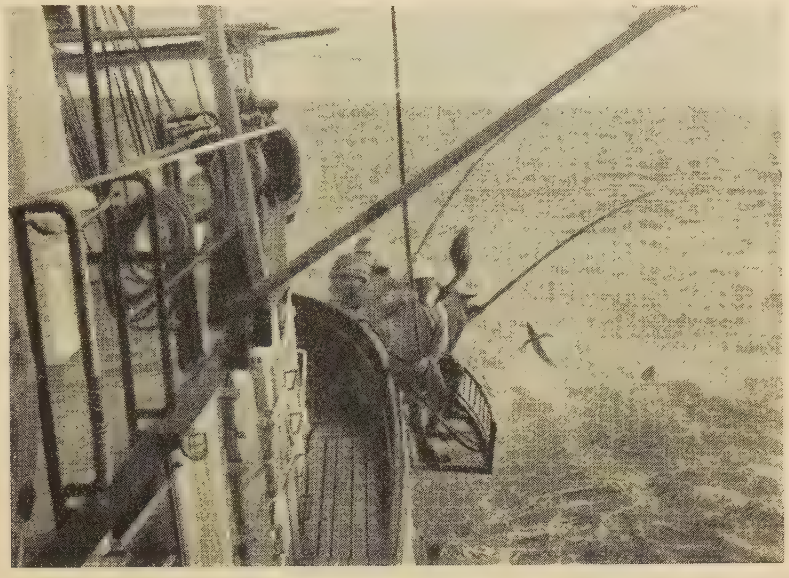


Figure 1. Tuna fishing from the port side and stern of the "Charles H. Gilbert." Small yellowfin tuna are being caught here, but the same technique is used for skipjack.

the accompanying bird flocks. The birds and tuna prey in common on small fish and squid, and, in order to engage the tuna, live-bait chum is used to divert them from their natural food. During fishing, sprays of water are directed into the sea around the stern where, according to the fishermen, they enhance the effects of the bait.

The HBL research vessel "Charles H. Gilbert", a 112 ft steel-hulled ship, was designed for a variety of research tasks including skipjack fishing. A view of the port side of this ship, looking aft, is given in Figure 1; four men occupy the two side fishing racks, while the pole of a fifth man is visible in the third (stern) rack. Above them, and partly obscured by pipework, is the "chummer" whose station is on top of a large baitwell, whence he throws live baitfish into the water near the fishermen's lures. The rack framework is composed of pipes carrying water for use as spray; a spraying nozzle is visible near the second fisherman's knee. Because of such factors as chum abundance, wake and stream flow effects, and possibly propeller noise, there is a gradient in fishing activity. Action is greatest beneath the closest fisherman in Figure 1 and least at the stern. For behaviour study purposes attention was focused on activity beneath the two side racks.

3. Evaluation of Observation Equipment

Ladder and diver

Our first attempt to place an observer underwater took place in June 1957. Because of the exploratory nature of the study, equipment was inexpensive and simple: A diver made observations from a 10 ft steel ladder on the ship's port side.

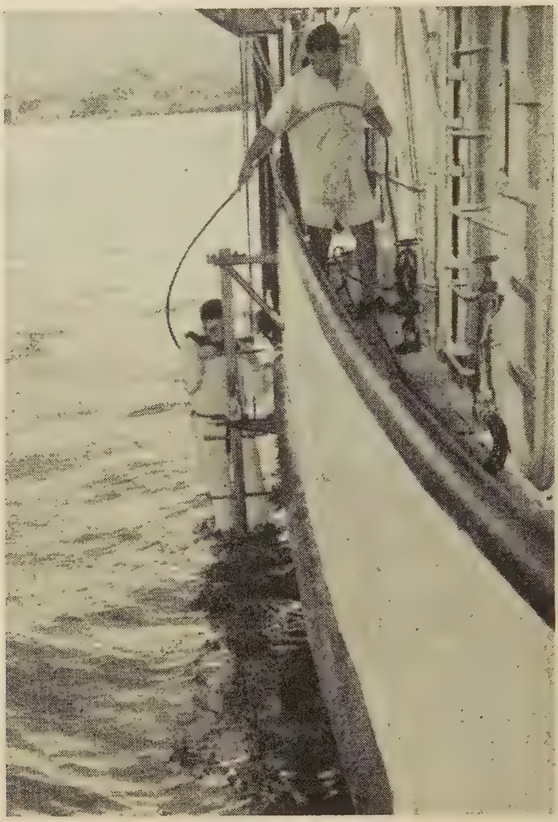


Figure 2. Diver descending overside ladder of "Charles H. Gilbert."

As shown in Figure 2, the diver was equipped with a face mask, mouthpiece, regulator, and hose leading to a bottled air supply on deck, a weighted belt, and protective diving clothing. He descended the ladder and crouched on its lower rungs, facing aft. Depending on his stance, his eyes were 1–2 ft beneath the surface. He carried a 16 mm Cine camera in a waterproof case, and between dives made voice records of his impressions. There was no provision for communication except a system of knocks on the ship's hull or ladder. The ladder itself was a 2 in. steel pipe with welded rungs of ½ in. steel bars. Three brackets held it to the ship while in use, and at other times it was pivoted out of the water as shown in Figure 3.

The diver-ladder technique was used only in bays, but it provided answers to several questions. It told us that a diver could be effectively positioned beneath the ship, and that bubbles from propeller cavitation were not a serious hindrance to his vision. Its cheapness and simplicity made this method a qualified success; its defects are listed below.

The method's principal disadvantages involved the diver's safety, utility, and comfort. The ship had to be slowed or stopped in order for him to ascend or descend the ladder, and once he was in place, speeds greater than about 3 knots tended to tear the mask from his face. The current, the ship's roll, and

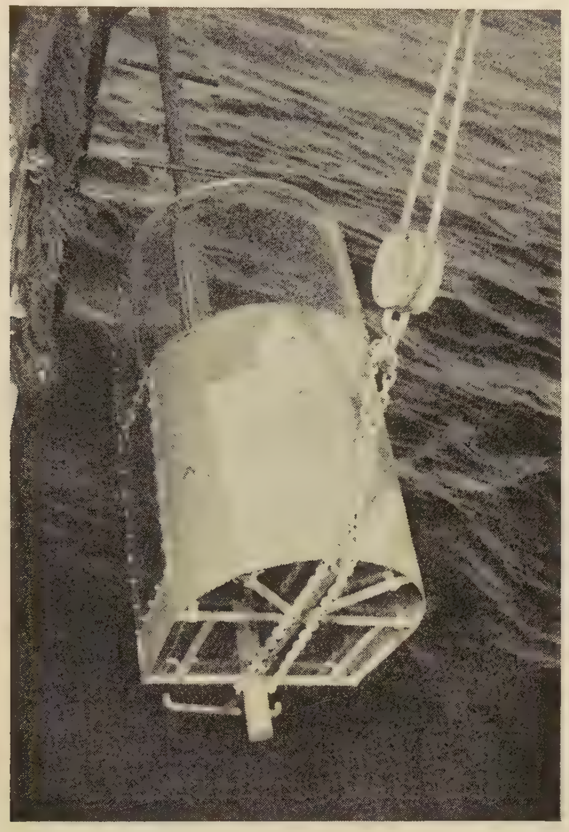


Figure 3. Shield used to protect diver on overside ladder.

ladder vibrations were sometimes sufficient to require his using both hands to remain on the ladder, thus prohibiting picture taking. The current rapidly chilled him, in spite of protective woolen and rubber clothing, and it also caused sore jaws from biting the regulator mouthpiece against the current's drag. Bubbles exhaled by the diver or dragged down around the ladder from the surface tended to obscure vision. There was an important time loss when he ascended to replace the film in his encased camera or to record his observations. Last, but certainly not least, was the psychological effect of being completely exposed during fishing in waters where sharks are common.

A solution to some of these problems was offered by partially enclosing the diver in a 4 × 2 × 2 ft U-shaped steel and plastic shield (Figures 3 and 4). Besides protecting him from the current and sharks, this provided a more comfortable place to sit. Squatting or kneeling on the transparent floor of the cage, he could photograph in response to knocks from the surface indicating a change of bait, etc. His forward and lateral vision was through windows of ½ in. transparent plastic; facing aft, where the skipjack were concentrated, there was nothing intervening except two ladder rungs. The shielded ladder was tested several times from June to August, 1957. These tests were quite rewarding, and following them it was decided that construction of a more permanent observation platform was warranted.

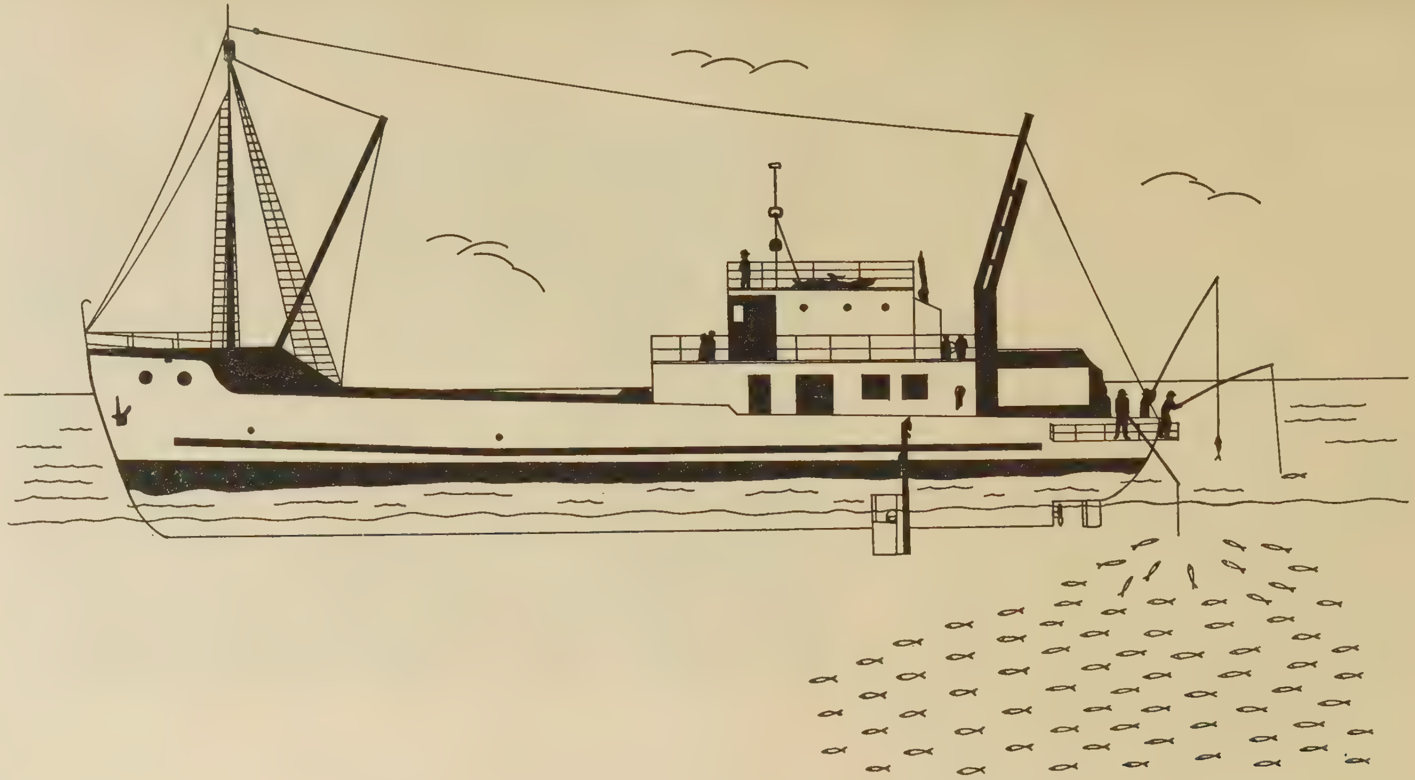


Figure 4. Position of shielded ladder and diver during skipjack fishing.

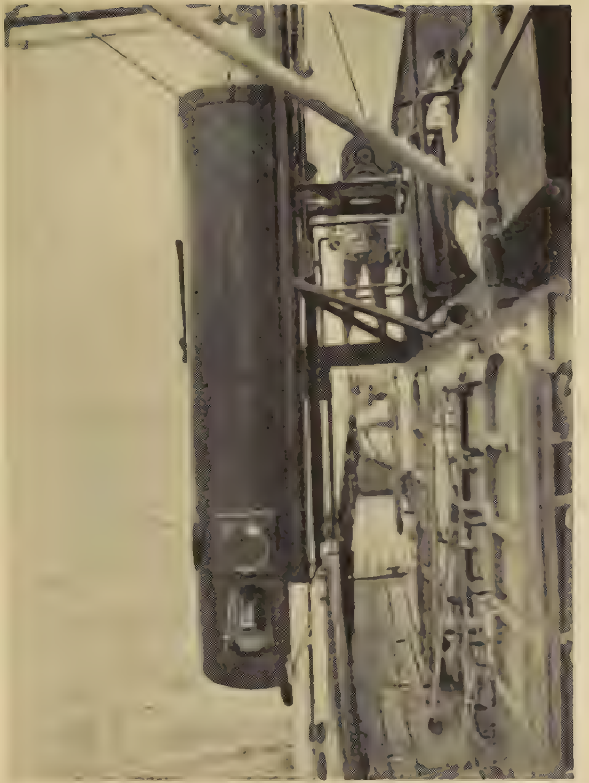


Figure 5. Observation caisson hauled from water after fishing.

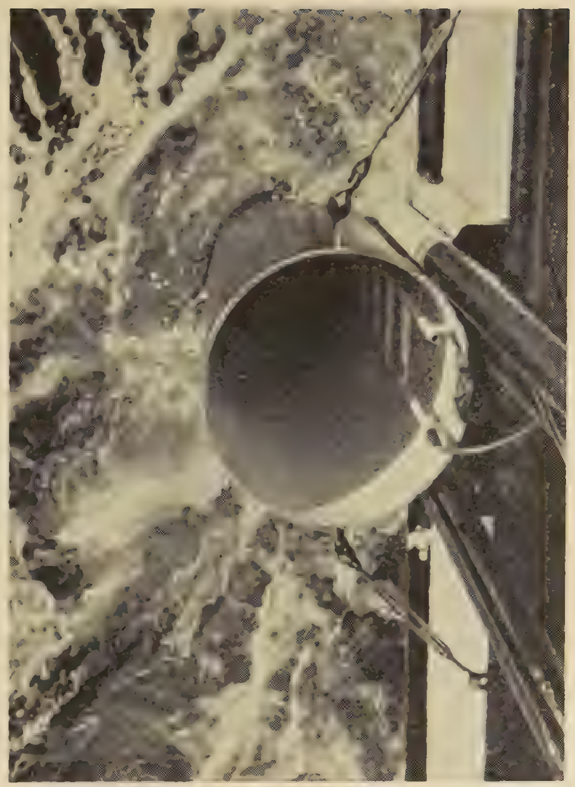


Figure 6. Caisson in its fully lowered position.
Note turbulence and bubbles.

Overside caisson

Many of the unsatisfactory aspects of the 1957 apparatus were inherent in the use of a diver. During the succeeding winter, therefore, plans were made for placing an observer beneath the surface in a retractable air-filled cylinder. Such a device was built in the spring of 1958, and was extensively tested on the "Charles H. Gilbert" during May-July. Observations made from this caisson have been discussed by STRASBURG (1959) and STRASBURG and YUEN (in press), but the apparatus itself has not been described.

As originally constructed (Figure 5), the caisson was a 11½ ft tube, open at the top, with four ports at its lower end. Just prior to fishing this tube was partially submerged by means of pulleys and a hand crank; after fishing it was raised from the water by its own buoyancy and the same pulleys attached in a different manner. The caisson was movably fixed to the ship by two 6 ft T bars which bore against the inside of extra-heavy slotted 4 in. pipes (Figure 6). A short length of pipe on the bottom of the caisson provided rigidity by fitting into a gudgeon 6 ft below the waterline. Accidental bobbing-up of the caisson was prevented by shackles, sister hooks, and turnbuckles securing it to the ship's rail in the lowered position (Figure 6).

An observer reached the viewing ports of the submerged caisson by a ladder. With his eyes 4 ft below the surface, he sat on a low stool and took moving pictures from a 5 in. forward port (½ in. plastic), a 12 in. side port, or two 10 in. after ports (side and after ports of ¾ in. glass). Communication with the surface was via a speaking tube leading to a recorder microphone. Fresh air was blown to the bottom of the caisson by way of one of the ladder's sidepieces (Figure 6). Water splashing over the top or leaking around the window seals accumulated beneath a false bottom, whence it could be drained by a valve or aspirated by a hose. In practise, except in all but flat calm seas, it was necessary to cover the top with a wooden hatch (not shown) to prevent flooding.

Some other statistics of the caisson are of interest in evaluating its utility. Its walls were of welded ¼ in. steel plate, and were not quite circular in cross section, being 28 × 30 inches in outside dimensions. The empty weight was about 1350 lbs. Water drag gradually misaligned the T bar bearings and their pipe guides, so that increasing amounts of time, up to 10 minutes, were required for lowering. This resulted in a costly pause, in terms of bait expenditure, while the crew hammered and tugged at the recalcitrant caisson. With the caisson lowered, the ship cruised at 7·5 knots instead of its normal 9, making it difficult to approach fast-swimming tuna schools. Even at this reduced speed bubbles blocked all vision except from the forward port. Dense clouds of bubbles were drawn down around the caisson and tended to collect in the recessed faces of the ports. At speeds of 2–3 knots (usual fishing speeds) turbidity was reduced to an occasional but annoying swirl of bubbles. Horizontal visibility was about 100–150 ft, depending on the object, but skipjack could be distinguished from other tuna species only to about 60 ft.

The caisson, as described above, was used to evaluate the effects of several fishing variables (dead bait, water sprays, various bait species, chumming rate, and sound) on skipjack feeding behaviour. Five weeks of such experiments provided ample opportunity for appraising the caisson. Turbidity provided the biggest problem, for bubbles sometimes rendered as much as 75% of the Cine camera film useless for detailed analysis. Another annoying feature was

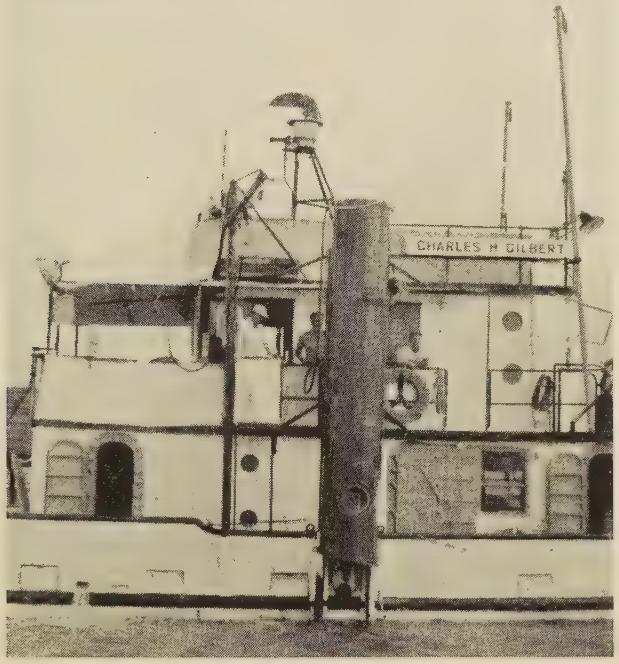
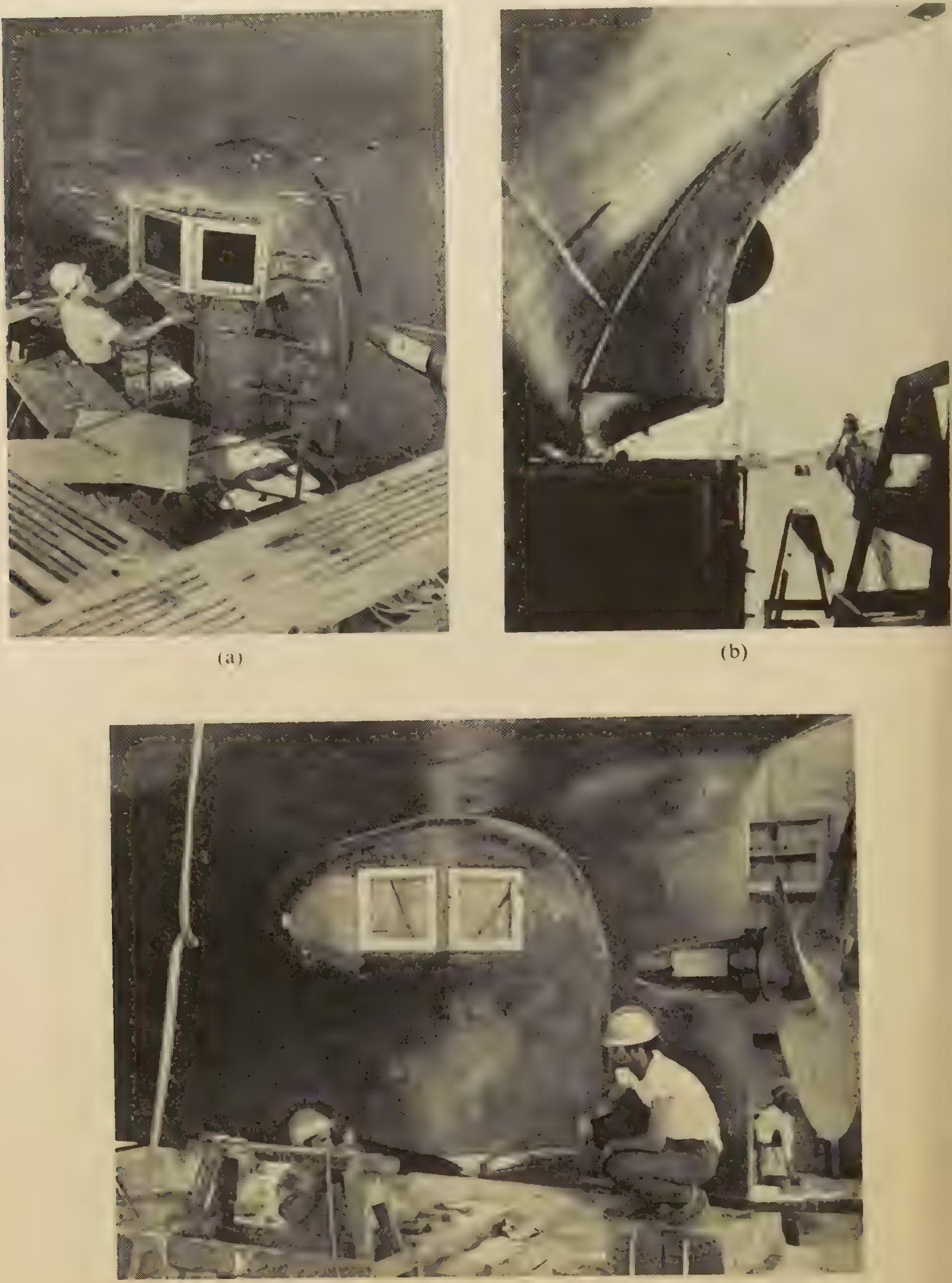


Figure 7. The redesigned observation caisson.

salt water splashing on the observer or his equipment, even with the top of the caisson covered (heavy seas sometimes opened the cover, drenching the observer). A third unfavourable feature was the restricted vision aft, where both ports were small and one slanted downward and was seldom used. Few tuna schools were lost because of the ship's stopping to lower the caisson, but this did happen occasionally and was not desirable. The advantages of the caisson over the preceding ladder are obvious and require no discussion.

The "Charles H. Gilbert" was engaged in other duties in mid-summer, 1958, so the caisson was temporarily removed and modified. Its height was increased by adding a 4 ft section to the top (Figure 7), and portions of the slotted pipe guides were removed in an attempt to reduce bubble formation. The two after ports were replaced by a single 12 × 24 in. pane of $\frac{1}{2}$ in. plastic. The hand crank for raising and lowering the caisson was removed, and power for doing this was instead supplied by the anchor winch. The improved 1600 lb caisson functioned satisfactorily during the period August–November, 1958. The added height kept out all water, and the enlarged after window gave increased latitude for picture-taking. The caisson could be lowered rapidly, often in $1\frac{1}{2}$ minutes, and there was little time loss from this factor. Shortening the pipe guides had no appreciable effect on turbidity, however, and this feature continued to be the most serious drawback to the caisson's use. By November 1958, it was decided that bubble-free vision was sufficiently important to justify new observation instruments.



(a)

(b)

(c)

Figure 8. (a) Fabricating metal portions of stern blister. (b) Profile view of stern blister. Windows are at vertical upper edge of blister. (c) Side view of completed stern blister. Windows and concrete fairing have been added.

Stern blister

An obvious means of reducing bubble interference was to place a window in the ship's hull below the waterline. This was regarded as a last resort, for it meant possibly weakening the vessel, relinquishing space needed for fuel, and perhaps reducing the ship's speed and steering qualities by the drag resulting from a protuberance. Nevertheless, in June 1959, the "Charles H. Gilbert" was placed in drydock and a convex observation "blister" added to the hull in communication with a former fuel compartment. Stages in the fabrication of this installation are shown in Figure 8.

Space for the observer was provided by welding a steel semi-cylinder, 22 in. in diameter and 3½ ft high, to the ship's skin outside the former fuel tank (Figure 8a). Surmounting this cylinder was a wide sill on which the observer could rest his arms or equipment. This sill was fronted by two 12 × 12 in. windows of 1 in. glass set 7 ft below the waterline. Steel reinforcing provided anchorage for an outer concrete coating which was sprayed on in liquid form, and hardened as a 1 to 12 in. layer which streamlined the blister. The completed structure, shown in Figures 8b and c, held two people, but only one could look out conveniently. The blister's bulge was minimal, and the ship cruised at 9 knots as before. Steering at normal cruising speed required no rudder compensation, but when maneuvering slowly, as in docking, the bow tended to starboard.

Observers enter the blister through a covered vertical access-way on the after main deck. A ladder and a series of steps lead to the semi-cylinder, where they can stand or sit comfortably. They and their equipment are dry at all times, and forced draft ventilation makes the blister one of the more pleasant places aboard ship. The previous bubble-turbidity problem is entirely eliminated, and objects such as sheets of newspaper or masses of *Sargassum* can be seen near the surface up to ranges of about 200 ft. Typical skipjack activity as seen from the blister is shown in Figure 9.

The blister was employed extensively during July–September, 1959. Observation from it was so easy, and occasionally so enjoyable, that in addition to experimental tests of skipjack behaviour, data were obtained on animals attracted to submerged lights, luminescent organisms, plankton net operation, composition of windrows of phytoplankton, underwater feeding of seabirds, and animals associated with drifting logs. Observations could have been made on bottom conditions and the undersides of waves.

As constructed the blister had two faults: its proximity to the tailshaft and propeller resulted in a high noise level, and its permanently submerged windows quickly became covered with sessile marine life. Noise ceased to be an important problem when sound-powered telephone headsets were used, and window cleaning required only a few minutes of a diver's time about twice a week.

Television

Concurrently with the first blister tests, we explored the use of closed-circuit television for studying tuna behaviour. Information was desired on the utility of a television camera mounted in the blister and another suspended over the side in a waterproof case. Skipjack activity recorded by these means was compared to that seen directly by eye, and to that recorded by a Cine camera

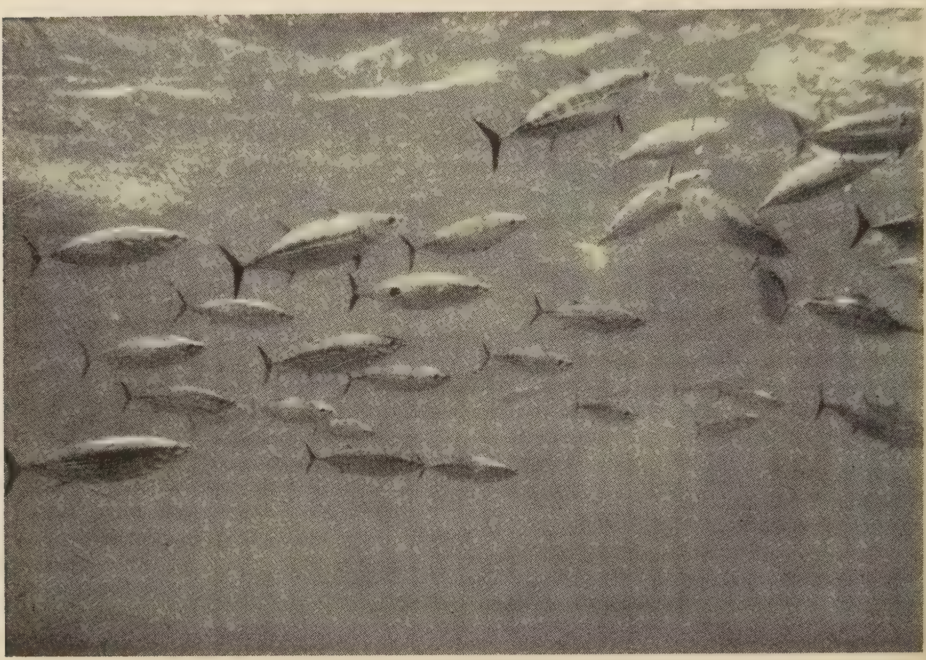


Figure 9. School of oceanic skipjack seen from the stern blister.

using colour film. Because only monochromatic television equipment was available, black-and-white Cine films were taken of the television screens.

An encased Vidicon television camera was attached to a rigid pipe framework and lowered over the side of the "Charles H. Gilbert" to the depth of the blister windows. Operations were coordinated, and fish scenes were observed, televised, and photographed simultaneously. Using 525 scan-lines per second and a 10 in. screen, the televised presentation was inferior to the eye's view. With television, fish outlines were indistinct, species could not be distinguished, contrast between fish and background was poor, portions of the screen were black, and a full-time technician was required to operate the controls. Substantially the same thing was shown by comparing the filmed versions of this, but here television appeared to have greater depth of field, and therefore more fish were visible. This virtue was offset by fluctuations in brightness and erratically moving horizontal bars, both possibly being synchronization phenomena. Television did not detect the numerous small animals swarming around a submerged light at night, but proved remarkably sensitive for observing bottom life. When the encased camera was lowered to the bottom in 92 ft of water, algae (*Padina*) and fish (*Acanthurus*) were easily identified, even during the rapidly changing light conditions preceding sunset.

Simultaneous operation of television and film cameras from within the blister was only partially successful. Apparently the ship's vibration affected the television camera, so that bright bars sporadically obliterated images on the screen. Exclusive of this, Cine camera or visual observation was still superior to the televised version.

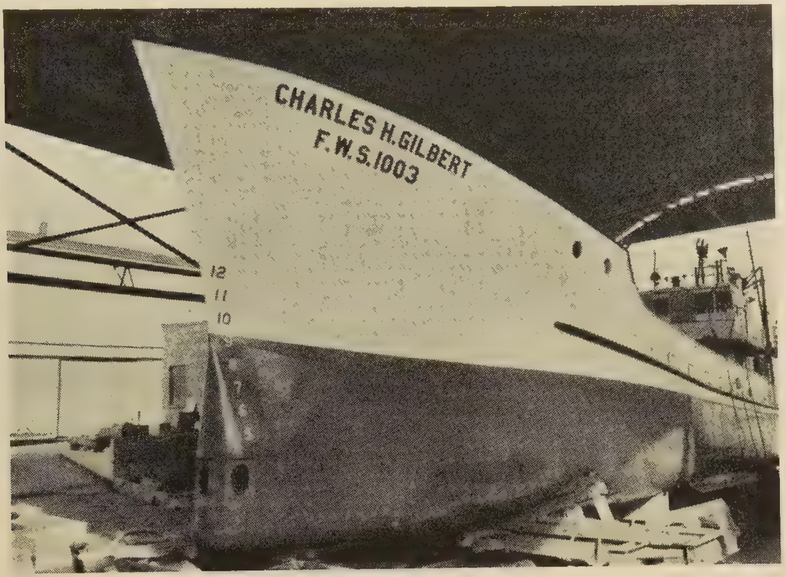


Figure 10. Construction of the bow blister on the "Charles H. Gilbert."

Bow blister

Although well adapted for observing feeding behaviour, the stern blister was too near the center of fish activity for out-lying skipjack to be seen. Thus we only suspect, and do not know, that the members of feeding aggregations are constantly leaving as they become satiated, and are constantly being replaced by hungry fish, the entire phenomenon being associated with a deep-swimming body of non-feeding fish. The physical dimensions and numbers of fish in a feeding aggregation are similarly difficult to ascertain. More information on these points could be obtained if the blister could be maneuvered around a school being fished by another ship. It is possible to do this with the stern blister but it will be much more easily accomplished with a similar structure located in the bow.

At this writing the "Charles H. Gilbert" is being fitted with the bulbous bow and observation blister shown in Figure 10. This blister is equipped with three 12 × 18 in. oval windows of 1 in. glass, behind which the observer will lie. His head will be 7 ft beneath the waterline, and his working space a long, high compartment, 3 ft wide. Access to the bow blister will be by ladder from the forecastle storage spaces, and communication is by sound-powered telephone. Ventilation is forced-draft.

4. Future Plans

An outstanding limitation of all the above approaches is that information is gained only about skipjack at or near the surface. Nothing is known of their activities at depths greater than about 100 ft, although there are indications that these activities may be significant. We have evidence (unpublished) that schools are attracted downward, in competition to our chum, by schools of natural food such as squid. Also, several hundred hours spent searching the surface layers from the stern blister have failed to reveal any really small skipjack. Fish weighing a pound or less should be much more numerous than the adults, and it can be surmised that they occur at depths greater than we can see.

For these reasons we are presently investigating the feasibility of constructing a small, fast, highly manœuverable submarine for studying skipjack behaviour to depths of about 400 ft. As envisioned, schools of adults would be located at the surface and followed downward, and underwater searches would be made for sizes not occurring at the surface. Observations would be by eye and camera through forward ports, and by television cameras facing in other directions. Acoustical apparatus and lights would aid in locating fish beyond visual range. Additional missions might include collecting plankton and water samples under selected conditions of depth, temperature, light intensity, or salinity; studies of biological sound, etc. An obvious failing of this method would be the near-impossibility of actually capturing skipjack, but this would be offset by the wealth of other information obtained.

5. Acknowledgements

Several members and former members of the Honolulu Biological Laboratory (HBL) staff participated in the design and use of underwater observational equipment. Mr. G. I. MURPHY initiated the investigation with an underwater ladder carrying a diver. MURPHY, V. E. BROCK, and the writers subsequently developed a dry caisson, and in the following years BROCK and the writers designed hull blisters and worked with underwater television. Messrs. H. J. MANN and A. K. AKANA, by drawing plans, fabricating models, and supervising construction, were closely involved with all such equipment, and their help is gratefully acknowledged. The photographs used in Figures 2 and 3 were supplied by the Honolulu Star-Bulletin.

6. Summary

Equipment for studying tuna behaviour underwater on the high seas is described. Starting with a ladder and diver, the staff of the Honolulu Biological Laboratory has progressed to a shielded ladder, an overside caisson, stern and bow blisters, and underwater television. Future plans involve a small, fast submarine. The principal faults and virtues of each device are noted.

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4.1 Implications for Fish Searching and Fishing Techniques

4.11 Preliminary Results of Underwater Observations of Tuna Schools and Practical Applications of these Results

Donald W. Strasburg and Heeny S.H. Yuen *

0. INTRODUCTION

Recent findings of the Pacific Oceanic Fishery Investigations (POFI) suggest that the oceanic skipjack, *Katsuwonus pelamis*, represe the largest tuna resource in the central Pac Ocean. Studies of larvae, capture of adults several methods, and sightings of surf

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* Fishery Research Biologists, Pacific Ocean Fishery Investigations, United States Fish and Wild Service, Honolulu, Hawaii

Proc. Indo-Pacific Fish. Coun. (III): 84 - 89, 1958.

hools all indicate that this species is not only idely distributed but also frequently abundant tropical and subtropical Pacific waters.

In spite of their distribution and numbers, ipjack are not harvested to the degree arranted by the world's increasing demand for otein. Probably the principal reason for this the fact that the fishery is prosecuted by live-it methods, for which the bait is usually licate (precluding long voyages to the fishing ounds) and in short supply. Several approaches the problem of increasing skipjack landings e therefore centered on the fishing method:) to develop gear to catch skipjack without it, (2) to use presently unexploited bait ecies, and (3) to increase the efficiency of the esent methods.

In the first approach are gill-netting and rse-seining, both of which have been tried by)FI, and neither of which has proved satisctory in tropical waters of the central Pacific. her baitless methods of capturing skipjack are ll being studied. POFI has also been inested in utilising new bait species and reasing the supply of the present kinds. The ults of these studies are promising but far m complete. In the third approach which is e subject of this report, POFI has studied the ssibility of increasing efficiency by modificans in techniques that might be suggested by ter understanding skipjack behaviour as ated to several fishing variables.

1. DESCRIPTION OF THE FISHERY

Before discussing skipjack behaviour it uld be well to describe the skipjack fishery as is now conducted in the Hawaiian Islands. e Hawaiian fleet consists of 26-30 vessels, ally known as sampans or aku boats ("aku" he Hawaiian name for skipjack). These ships from 60 to 80 ft. long and weigh 27-77 tons. eir crews number 7-15 men, all but two of om fish. The deck house is located well ward, leaving a clear working space of -600 square feet aft. In this space are ated wells for carrying live bait and iced rage spaces for keeping the catch. Around stern is a series of pipes fitted with nozzles; en fishing is in progress sea water is pumped ough these pipes to produce a spray that kes the sea and supposedly enhances the cts of the bait employed.

After obtaining a sufficient quantity of live bait, usually nehu (*Stolephorus purpureus*, a small anchovy), from inshore waters, the sampans depart for the fishing grounds, getting under way before dawn so as to make maximum use of daylight while on the grounds. A considerable part of their day is devoted to scouting for tuna, by searching for flocks of sea birds with the aid of binoculars. These birds feed on the small fish and squid driven to the surface by skipjack, and their presence is thus indicative of tuna. When a feeding bird-flock is sighted it is approached and when the boat is judged to be close enough, one of the fishermen throws live bait into the water as chum, and if this is successful the skipjack school converges on the bait. The water sprays are then turned on so that droplets strike the sea in a large arc around the rear of the vessel, and the fishermen take their places at the stern.

Fishing is done with bamboo poles equipped with jigs of various sorts, the hooks of which are barbless and nearly always unbaited. Jigs are cast into the water where the sprays strike, and the combination of the activity of the live-bait, the spray splashing, and the fall of the jigs resembles the effects produced by a school of small fish. A hooked skipjack is pulled from the water and caught under one arm by the fisherman, who slides the hook from its mouth, throws the fish on the deck behind him, and returns his jig into the water. Fishing usually lasts 15-20 minutes; when it ends the fish are iced, the deck cleaned, and another school sought. Because of bait mortality and the fact that the catch is iced rather than frozen, fishing is done within 100 miles of shore, and typical trips are of only one day's duration. The catch per trip may amount to as much as 40,000 lbs. of 3-35 lb. fish. During the summer skipjack season most of the catch is composed of 18-22 lb. fish.

2. UNDERWATER OBSERVATIONS

POFI's initial work on tuna behaviour has been an attempt to assay several of the variables apparent in fishing conducted as above. Among the items investigated were the effects of: water sprays, chumming rate, live versus dead bait, noise, various bait species, and seepage into the fishing area of certain body fluids from fish lying on deck.

These variables were studied both from the surface and from an underwater observation chamber attached to the side of the POFI research vessel *Charles H. Gilbert.* The observation chamber is a 14 ft. steel cylinder equipped with windows at its lower end, and mounted so that it can be lowered until the windows are 6 ft. beneath the sea surface. Coloured movies were taken of underwater tuna activity, and were supplemented by recorded spoken comments from underwater and surface observers. Catch rate was noted by ringing a bell each time a fish was hooked, the bell tones also being recorded. In addition, samples of the fish caught were measured and their sex organs and stomach contents examined.

The following routine was used in conducting sea experiments on skipjack. Baiting and scouting were done as in the commercial fleet, with the exception that this work would be done only in sunny weather and relatively calm seas. The former prerequisite ensured sufficient light for underwater photography, the latter reduced turbulence and splashing into the open top of the observation chamber. Part of the illumination problem was solved by selecting a relatively fast colour film with which pictures would always be taken between about 9 a.m. and 4 p.m. unless the sky was heavily overcast.

When a skipjack school was encountered it was approached closely and chumming begun. If tuna responded to the chum, the chamber was lowered rapidly (1½ minutes) and the vessel's speed decreased to reduce turbulence and allow fishing to commence. In most cases the initial fishing was done in commercial manner and the exposed to record skipjack behaviour under film these conditions. In nearly all experiments periods of "commercial" fishing alternated with experimental fishing, this being necessary in order to detect changes in behaviour with time, i.e., skipjack activity could change as the appetite for bait became satiated.

Before discussing the experimental results it would be well to mention the general appearance and behaviour of a typical school of feeding skipjack. In Hawaiian offshore waters an underwater observer's field of vision extends to about 60 ft. for skipjack. Tuna of more than 5 lbs. weight are identifiable to species within this range, although it is difficult to see their distinctive colour patterns in the outer parts of this field. Probably of greatest interest in live skipjack identification is the optical suppress of the blackish belly stripes and the promine given to a series of dark spots resembling marks along the midsides. These spots disap immediately after a skipjack is landed, at wh time the familiar dark belly stripes become m more noticeable than they ever are when s underwater.

The activity of skipjack varies marke with size. The smallest skipjack seen w about 20 cm. in length, and thousands of th fish schooled together. Such schools w noteworthy for their seemingly instantane response to stimuli, precision in manoeuver and the close spacing of individuals. In c parison to larger fish, it seemed that school was a dominant trait in the behaviour of th small fish, for the schools never entirely disru even during feeding.

In medium - sized skipjack (45 - 65 cm. 4 - 14 lbs) activity was frenzied and m semblances of schooling were lost during feed The fish made rapid dashes to the surface, ei singly or in pods of half a dozen fish, at spe difficult to measure but probably close to knots. Such fish pursued chum at veloci sufficient to carry them out of visual ra Their swimming was seldom horizontal instead oscillated vertically in a pattern res bling a series of sine curves.

Large skipjack (70 - 80 cm., or 18 - 28 l appeared to be almost lethargic in compari with the smaller individuals. There were signs of schooling during feeding, and the never appeared to swim faster than abou knots (more often they cruised along at knots). Their swimming was horizontal nearly so, and surface dashes were relati unhurried.

3. EXPERIMENTS

The following comments on skipj behaviour were derived from only three mon work, a large part of which was devoted developing observational techniques and sea ing for tuna upon which to experiment. Beca the data are few and only incompletely analy it must be emphasised that the conclusions tentative.

One of the first fishing variables exami was the effect of water sprays on skipj behaviour. Four skipjack schools were fis vhile the sprays were turned on and off at ntervals. Differences between the sprays-on nd sprays-off conditions were not striking, the eneral picture being that the fish remained ear the surface (1-3 ft. depth) with the sprays n but deeper (6-20 ft.) with them off. There vere more dashes to the surface when the sprays vere on, and the catch rate was also higher at his time. All of these phenomena are tendencies ather than distinctly overt responses, for they vere seldom all observed at the same time. It vould seem that water sprays cause more tuna o be caught by increasing their feeding frenzy, ither by making it seem that the baitfish are nore numerous and by enhancing their apearance, or in some other manner.

The second fishing variable studied was e response to live and dead chum. As entioned earlier, the baitfish normally used was ehu. Schools of skipjack were twice brought the stern with live nehu, and then chumming as alternated between live and dead nehu. ecause of their delicate nature some nehu were ead or dying during the "live" bait parts of e tests, and skipjack were observed to eat litary dead individuals under both experiental conditions. It could not be determined hether skipjack actually ate quantities of dead hu in the "dead" bait sequences, but occaonally they swam through dense masses of dead it seemingly without consuming any of them. partial explanation of our failure to detect eding here is the fact that as more and more ad nehu entered the water the swimming eed of the tuna decreased, dashes to the rface became infrequent, and the skipjack fell ern of the vessel where they were not clearly ible to us. Had their falling behind been owed to continue, the tuna school would have en lost. Switching to live bait at this juncture ulted in the skipjack returning to the fishing a, increasing their swimming speed, and king numerous dashes to the surface.

Experiments have been designed to be de in the future to determine whether mixes of live and dead nehu constitute acceptable m for skipjack. If they should prove to be the fishermen could effect a considerable tsaving, which would be a great advantage ce bait mortality is now a serious problem. o to be investigated is the problem of whether pjack eat dead chum without prior or coning stimulation by live chum. Knowing something about this is vital in evaluating the stimuli released by bait, and could lead to the selection of better bait species and lures, or to the more efficient use of present kinds.

Another fishing condition examined was the rate of throwing chum. Although this varies with the type of school and the phase of fishing, there exists a normal rate which preliminary calculations show to be about 1½ lbs. of bait per minute. For the experiments undertaken, the normal rate was considered as standard, twice the normal rate as fast, and half the normal rate as slow. The chumming rate was varied during the course of fishing three skipjack schools, each of which was first brought near the vessel with chum thrown in the usual amounts.

When small schools were subjected to fast chumming, more nehu than the skipjack could consume soon accumulated. The swimming speed of the tuna increased as they pursued the abundant food, but because the nehu tended to drop astern of the vessel, the feeding tuna were also left behind, resulting in decreased catch. This was not true for large schools in which the fish were sufficiently numerous to cope with the chum immediately. In such cases activity was not increased and the behaviour of the fish appeared to be the same as that when the chumming rate was normal.

With slow chumming the skipjack swam at lower speed and tended to scatter; vertical movement, which appears to be a part of the feeding frenzy, ceased, and the tuna remained close to the surface. Clearly slow chumming provided too little food to elicit a desirable feeding response, in contrast to rapid chumming which made the bait more attractive than the jigs. Switching to normal chumming rate resulted in a return to a desirable degree of activity.

Another variable subjected to test was the effect of vessel noise on skipjack. Sound was produced by hammering on the ship's metal hull from within the engine room, but no differences in behaviour were detectable between the noise and no-noise conditions in the single school tested.

Two other bait species were compared to nehu with respect to their effects on skipjack behaviour. For these tests skipjack were first brought to the stern with nehu, and then chumming was alternated between nehu and the species under test.

Tilapia mossambica 1½-2 inches in length were tried on one skipjack school. Skipjack were not observed to feed on tilapia, their speed and frequency of dashing to the surface slackened, and they tended to group together in a partial school formation. The catch rate dropped off at the same time. Chumming was twice switched back to nehu upon which the tuna lost all semblances of schooling and their activity increased markedly. Tilapia were available for behavioural testing only on this single occasion, the results of which are at variance with numerous other trials where skipjack responded as favourably to tilapia as to nehu. Differences between the behaviour of tilapia and nehu are the subject of future studies in which it is hoped to learn more of the qualities of a desirable bait.

Approximately 150 *Dorosoma petenensis* (threadfin shad) were chummed alternately with nehu while a school of skipjack was being fished. These shad were silvery in colour, about 3-4 inches long (twice the size of nehu), and rather deep bodied, so that they were quite conspicuous as compared to nehu. Presumably their greater size and conspicuity caused the shad to be more readily taken than nehu, and these factors also caused their predators (skipjack) to strike them from greater distances and at higher velocities. The momentum of skipjack eating shad carried them away from the fishing area. Moreover shad that escaped immediate consumption took up a position 15-20 ft. from the vessel whereas nehu took up a position 2-10 ft. from the vessel, and this relative remoteness of shad as bait caused relative dispersal of the tuna preying on them. When shad were used as chum the catch rate declined, not only for the above reasons, but probably also because the lures in use were designed to compete with nehu, not with the more conspicuous shad.

Although threadfin shad and nehu had about the same swimming speeds, the use of the former caused a general dispersal of the skipjack. There is little doubt that shad are desirable bait, particularly if their high conspicuity causes the tuna to draw in from greater distances. It would be desirable for shad to remain closer to the fishing vessel, however, and perhaps this can be achieved by subjecting them to tranquilizing drugs prior to use as chum, an experiment planned for the future.

Two other effects of fishing were e
amined, both dealing with variations in skipja
behaviour caused by draining of fish body flui
from the deck of the fishing vessel. Fisherm
believe that blood from the catch draining in
the fishing area causes skipjack to becon
frightened and to cease biting. In commerci
fishing therefore, all scuppers and other ope
ings in the deck are plugged during skipja
fishing, and every effort is made to confine blo
from the catch to the deck. To test this,
gallons of blood were obtained from livi
skipjack and mixed with an equal volume
glycerol-citrate anticoagulant. The resultant
gallons of preserved blood were sprayed into t
sea at intervals during fishing. The blood mix
with sea water quite well, forming a transpare
cloud of a light red colour, through whi
skipjack moved at random, showing no sig
of fright or other abnormal behaviour. As fishi
progressed numerous skipjack accumulated
deck, and blood from them was allowed to dra
into the sea through the scuppers. Here t
skipjack were observed to enter the stained wa
freely with no apparent changes in behavio
Later the ventral aorta was severed in half a doz
skipjack, and these still-living fish were toss
into the fishing area. The bleeding tuna sound
vertically upon striking the water, but in
case did they or their blood produce any respo
from other skipjack.

A second test was devised to determi
whether the expected behaviour changes w
caused by the colour of the blood or its chemi
properties. Inert red food colouring was spray
into the sea in the same manner as blood h
been, but because it was highly concentrat
this dye formed a deep red-purple cloud whi
was opaque in many places. Without excepti
the skipjack avoided this deeply stained ba
of water, swimming around or beneath it
never through it. Five to ten minutes later
ship entered the dyed area again, the col
having diffused considerably in the meanti
Although the sea water was still purplish
colour it was transparent, and skipjack igno
the dye so far as could be determined.

The results of these tests are interest
in that the blood experiment tentatively
proves a rather firmly entrenched belief, wh
that with dye suggests that skipjack co
perhaps be guided or even corralled by a
ficiently dense wall of colour. Experime

ing lampblack to create a very dark wall of lour are now being undertaken, with the idea at if a skipjack school can be contained within ch a wall, then perhaps dyes will become luable adjuncts to purse-seining or gill-net- ig. Academically the lampblack tests are of erest for the information they may yield about e utility of "smoke screens", such as the ky clouds produced by squid, against natural edators.

In addition to blood, a certain amount of in slime drains from the catch during fishing, d it was thought that this might contain the rine — or pterine — like substances noted by n Frisch (1942) as causing a fright reaction fish. To see whether this occurred, crude tracts were prepared from fresh skipjack skins removing all flesh, cutting the skin into ces, and then reducing it to a semi-fluid by ans of an electric blender. One lot of the ultant liquid was filtered to give a pale straw oured, transparent fluid, the other was left in natural grey, opaque state. Both solutions re sprayed into the sea during fishing, but no anges in skipjack behaviour were seen, and tainly no fright reactions were produced. It uld be noted, however, that it was uncertain ether the extracts actually contained the rines or pterines in question.

4. CONCLUSIONS

Summarising the results of the above periments, it is apparent that successful skipjack fishing depends upon disrupting the schooling tendency by creating and maintaining a feeding frenzy. This activity seems to be released initially by the movements of small silvery prey, and it is enhanced by spray droplets striking the water. If the feeding stimulus is made too intense by using too attractive or too abundant bait, the fishing jigs are ignored, and if it is too small, such as when unattractive or insufficient bait is used, skipjack either scatter or re-form into schools. Neither sound, blood or skin extracts appear to have much effect on actively feeding skipjack.

These conclusions are derived only from a small body of data, but in spite of this disability it is apparent that behaviour studies may be of aid to the fishery. As more is learned about bait-skipjack interactions, it becomes easier to select desirable bait species, and experiments such as the dye tests may lead to the development of entirely new fishing methods. The accumulation of more or less academic information on the structure of skipjack schools may also be of value in explaining certain vagaries of fishing: what portion of a school actually feeds at one time, whether skipjack or bait will approach a hull of one colour more closely than another, etc. Thus we feel that skipjack behaviour studies have direct practical application to problems of the fishery, as well as being of considerable academic interest.

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JAPANESE SUMMER FISHERY FOR ALBACORE (*GERMO ALALUNGA*)

RESEARCH REPORT 52

FISH AND WILDLIFE SERVICE

UNITED STATES DEPARTMENT OF THE INTERIOR

ABSTRACT

The important albacore fishery carried on by a fleet of Japanese live-bait tuna boats in the spring and early summer in the northwestern Pacific is described. An account is given of the historical background of the fishery, and the magnitude of its production is compared with other Japanese albacore fisheries and with the United States west coast fishery. The seasonal trends in landings, geographical distribution of bases and fishing grounds, and the marketing and utilization of the catch are discussed. The fishery is shown to be the largest in the world for this species, although only a recent outgrowth of, and still subsidiary to, the Japanese skipjack fishery, and to be largely dependent on foreign markets for its support.

JAPANESE SUMMER FISHERY FOR ALBACORE (*GERMO ALALUNGA*)

By WILVAN G. VAN CAMPEN
Translator

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CONTENTS

Page
Introduction 1
Development of albacore summer fishery 3
Physical setting of the fishery 6
    Fleet bases 6
    Fishing grounds 10
    Season and water temperatures 13
Fleet and operating regime 16
    Fishing method 19
    Bait 20
    Ice 21
Size of fish 22
Marketing and utilization 23
Summary 26
Literature cited 27

JAPANESE SUMMER FISHERY FOR ALBACORE *(GERMO ALALUNGA)*

Japan is by far the world's greatest producer of albacore tuna (*Germo alalunga*). Since 1952 the Japanese annual landings of this species have been from two to three times as large as those of the United States, the second largest producing nation (table 1). All but a negligible fraction of the Japanese catch comes from the following three sources: Pole-and-line fishing with live bait, mainly in the spring and early summer, in the North Pacific east of the home islands; longline fishing, principally in winter, in the western and central North Pacific; and longline fishing throughout the year in the tropical Pacific and Indian Oceans. Landings of tropical albacore make the smallest contribution to the total, although they have increased sharply in recent years, as indicated by catch data from the operations of mothership fleets (table 2). The longline and the pole-and-line catches from the North Pacific have been of comparable size in several of the years for which records are available; however, despite occasional years in which the longline catch has exceeded the pole-and-line catch, the latter is normally the biggest element in the Japanese albacore landings (table 3).

Table 1.—Annual landings of albacore on the Pacific coasts of Japan and the United States, 1930–56

[In tons]

Year	Japan [1]	United States [2]
1930	17, 615	143
1931	20, 000	18
1932	15, 840	310
1933	17, 437	1
1934	12, 557	60
1935	16, 787	1, 193
1936	10, 600	492
1937	14, 804	1, 760
1938	16, 000	8, 848
1939	18, 818	9, 459
1940	20, 330	7, 250
1941	-----	5, 966
1942	-----	10, 458
1943	-----	14, 009
1944	-----	26, 397
1945	-----	19, 741
1946	902	12, 070
1947	9, 535	13, 422
1948	8, 083	24, 680
1949	20, 572	27, 397
1950	32, 628	36, 207
1951	32, 999	17, 245
1952	65, 788	26, 278
1953	56, 985	17, 417
1954	57, 145	13, 499
1955	44, 724	14, 866
1956	64, 675	20, 310

[1] The 1930 figure is from Aikawa (1949, p. 456), where the source is identified only as Agriculture and Forestry Statistical Tables. The figures for 1931 to 1937 are from Hasegawa (1938). The 1938 figure is from Machino (1949) and was estimated by him from the number of fish landed. Figures for 1939, 1940, 1950, and 1951 are from Survey of the Domestic Tuna Industry (Anderson et al., 1953). The 1946 to 1949 figures were taken from or deduced from data in Katsuo to Maguro, Japan Federation of Tuna Fishery Cooperatives Nos. 5, 16, and 26; they were noted in the source as probably 25 to 33 percent incomplete. Figures for 1952 to 1956 are from annual reports of catch statistics published by the Statistics and Survey Division of the Japanese Ministry of Agriculture and Forestry. It should be noted that various sets of catch statistics available present many large discrepancies, and their accuracy is dubious.

[2] The figures for 1930 to 1943 and 1950 and 1951 are from Survey of the Domestic Tuna Industry (Anderson et al., 1953). Figures for 1944 to 1954 are otherwise from Fishery Statistics of the United States, the U.S. Fish and Wildlife Service. The 1954 to 1956 figures are from published data of the Fish and Wildlife Service and California Division of Fish and Game.

Note.—The author is now Fishery Attaché, United States Embassy, Tokyo, Japan.

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Table 2.—Albacore landings of Japanese mothership fleets and foreign-based operations, 1950–56

[In tons]

Year	Mothership fleets	Foreign bases
1950	48	------------
1951	137	------------
1952	79	------------
1953	320	------------
1954	3, 920	270
1955	5, 409	3, 228
1956	4, 069	3, 781

Sources: Annual Reports of Catch Statistics, Statistics and Survey Division, Japanese Ministry of Agriculture and Forestry; 1956 figures ascribed to Japanese Fisheries Agency in Weekly Report No. 49 of the Tuna Research Foundation Division, California Fish Canners Association.

Table 3.—Albacore catches of the Japanese pole-and-line and longline fisheries, 1931–37 and 1946–56

[In tons]

Year [1]	Pole-and-line	Longline
1931	12, 000	8, 000
1932	8, 910	6, 930
1933	9, 712	7, 725
1934	7, 376	5, 181
1935	4, 816	11, 971
1936	1, 600	9, 000
1937	804	14, 000
1946	------------	902
1947	7, 303	2, 232
1948	1, 932	6, 151
1949	6, 650	13, 922
1950	14, 179	18, 423
1951	15, 984	12, 549
1952	46, 109	19, 401
1953	36, 301	20, 522
1954	30, 950	26, 145
1955	26, 724	17, 842
1956	36, 801	17, 379

[1] The figures for 1931 to 1937 are actually given in the source as summer (May–July) and winter (October–April) catches, and probably do not represent with complete accuracy a breakdown by fishing method.

Sources: The figures for 1931 to 1937 are from Hasegawa (1938). (The same figures appear in the journal Kaiyo Gyogyo, No. 4, 1936, for the period of 1931 through part of 1936, and are there ascribed to Operations Reports of the Frozen Tuna Association.) The figures for 1946 to 1951 are drawn from data in Katsuo to Maguro, Nos. 5, 16, 26, and 28, Japan Federation of Tuna Fishery Cooperatives, where some of them are noted as being probably 25 to 33 percent incomplete. Figures for 1952 to 1955 are from the Annual Report of Catch Statistics, Statistics and Survey Division, Japanese Ministry of Agriculture and Forestry, for the year concerned. The 1956 figures are taken from Weekly Reports Nos. 30 and 42 of the Tuna Research Foundation Division, California Fish Canners Association, where they are referred respectively to a trade newspaper and to the Japan Federation of Tuna Fishery Cooperatives.

It is this pole-and-line, live-bait albacore fishery, carried on in spring and early summer in the western North Pacific, that is th subject of this paper. The materia for the paper is drawn almost entirely from publications, most o them Japanese, and to a slight extent from firsthand observation an from personal communication wit Japanese authorities. Unfortunately, many aspects of the fisher do not appear to be well documented. There is, as far as th writer knows, no comprehensiv treatment of this important fisher in the Japanese literature. A sligh digression here may explain th apparent neglect on the part o Japanese writers. Basically, th Japanese draw a sharp distinctio between the terms "katsuo," whic is similar to the broad usage of th English "bonito" in that it mean specifically the skipjack but includes generically several othe small, striped tunalike fishes, an "maguro," specifically the bluefi or black tuna, but including gene ically all of the larger tunas—th yellowfin, bigeye, and albacore- and in older usage, even the spea fishes. On the basis of this distin tion, the Japanese customari speak of their katsuo fishery (th is, the pole-and-line, live-bait fis ery, which has the skipjack as i primary object) and their magu fishery (the tuna longline fisher which takes a variety of tunas well as spearfishes and sharks Albacore, the smallest of the m guro, are taken by both fisheries b are of primary importance in ne ther, and thus they tend to be ove looked when general treatises either fishery are written by nati authorities.

Another point of caution when using the Japanese literature on albacore fishing is that Japanese writers often imply that all pole-and-line fishing is done in the summer and all longline fishing in winter, whereas the real picture seems to be a bit more complex. Apparently, some albacore are taken by both methods in all months of the year, and it appears that some boats, particularly in winter, go to sea prepared to use both techniques, setting their longlines and then scouting the vicinity of the set for surface schools which can be fished with live bait.[1] It is doubtful, therefore, whether the published statistics, such as those in table 3, give a completely accurate breakdown of the albacore catch by fishing method.

DEVELOPMENT OF ALBACORE SUMMER FISHERY

The Japanese pole-and-line fishery for skipjack, of which the summer fishery for albacore is an outgrowth, is of considerable antiquity. The oldest Japanese history, the semilegendary Nihongi, mentions skipjack angling in the year 124 A.D. by the Emperor. A later hronicle, Hojo Godaiki, in a reference to events in 1537, describes the annual summer migration of the kipjack northeastward along the Japanese coasts, and a work published in 1798, Sankai Meisan Zukai, mentions the use of live bait and pictures horn and feather lures similar to those in use today. (These historical notes are from Yamaguchi 1947.) Thus, the fishing technique appears to have evolved to nearly its present form by the end of the 18th century. Further development of the fishery had to wait on the adoption of engines for propulsion and the construction of larger vessels along western lines. These changes began in the first decade of the present century and have continued to the present day.

It is doubtful whether the Japanese pole-and-line fishery took many albacore in its early years.[2] For one thing, the small sail- and oar-propelled vessels in use before this century worked only a few miles offshore, fishing schools of skipjack which, according to some Japanese authorities (Imamura 1953; Yamaguchi 1947), used to migrate much closer to the coasts than they do now. Nowadays, at least, the albacore seem to approach the coast less than the skipjack, as evidenced by the fact that in 1953, for example, albacore made up only 4 percent of the catch of the large fleet of coastal (less than 20 tons gross) live-bait boats as compared with 33 percent for the high-seas (more than 20 tons) fleet (Japanese Ministry of Agriculture and Forestry, 1955). For another thing, the pole-and-line method permits the fisherman to select to some extent the kind of fish that he will try to catch, and the albacore has never been a prized species for domestic consumption in Japan. The Japanese customarily eat fresh tuna raw; otherwise they preserve the fish, principally skipjack, by boiling it and drying it very hard (katsuobushi). The albacore, with its soft, pale flesh, is not very suitable for either use.[3] In the days before the export trade in albacore arose, the Japanese longline fishermen, whose fishing method is less selective than that of the pole-and-line fisherman, regarded the albacore as a bait-stealing pest and shifted to new fishing grounds when too many of the long-finned tuna were hooked on their lines. It seems probable, therefore, that for more than 2 decades after large, powered skipjack boats began to operate far enough offshore to be in albacore waters the production of this species was low in Japan.

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[1] For example, a Tokai University Industrial cience Laboratory fishing situation report for ebruary 21, 1957, has more than 100 boats making good catches of 8 to 14 pound albacore n pole and line close in to the northeast coast f Honshu.

[2] Linguistic evidence indicates a closer and longer familiarity of the Japanese with the skipjack than with the albacore. The word for skipjack, "katsuo," is not readily analyzable, although a traditional etymology derives it from "katai uo," literally hard fish. The two common names for the albacore, "bincho" or "binnaga maguro" and "tombo shibi," on the other hand, apparently are comparatively recent formations meaning long-sideburn tuna and dragonfly tuna.

The summer fishery for albacore, as a deliberate diversion of fishing effort from skipjack to albacore, is a development of the last 30 or 35 years. It arose in response to the requirements of California packers, who had built up a market for canned white-meat tuna only to find themselves without raw materials as a result of the failure of the California albacore fishery in the late twenties and early thirties. It is maintained, despite the recovery of the United States west coast fishery, because of a continuing demand in the United States for frozen and canned Japanese albacore. Without this export market, there is little doubt that the Japanese live-bait fleet would shift much of the effort expended at present on albacore fishing to fishing for skipjack and small bigeye and yellowfin.

The total annual production and export of Japanese albacore through the 1930's and up to World War II showed considerable variation from year to year but no consistent trends (tables 1 and 4). What the total figures do not show, however, was the drastic drop in pole-and-line catch in the late thirties (table 3). A concerted effort was made to compensate for this decline by increasing the longline catch. Exploratory fishing vessels of the Japanese Government scouted summer longlining grounds as far away as the Midway Islands area, and research was done on the problem of "green meat," which was more acute in albacore taken by longline than by bait boats.

No production figures for the wa years have been found, but it i clear that albacore fishing continued at least into 1943 (Kimura 1949). At that time the wartime food shortages probably supplied an incentive sufficient to replace the vanished export market. During World War II, the larger fishing boats were gradually taken over b

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[3] Market reports in Japanese trade journals have occasionally recorded high bids for small quantities of small albacore by manufacturers of dried tuna loins, which indicate a certain demand for this unusual product.

Table 4.—Japanese exports of frozen and canned albacore, 1931–39

Year	Frozen (tons)	Canned	
		Cases	Tons of raw material
1931	3, 672	28, 359	567
1932	1, 274	258, 026	5, 106
1933	1, 699	680, 282	13, 606
1934	2, 070	281, 715	5, 634
1935	3, 444	458, 354	9, 167
1936	2, 928	480, 308	9, 616
1937	3, 712	781, 053	15, 621
1938	2, 253	322, 043	6, 441
1939	3, 532	788, 759	15, 755

Sources: Figures on frozen exports are from Survey of the Domestic Tuna Industry (Anderson et al., 1953) and are said to cover exports to the United States and Canada only. Figures on canned exports are from Shapiro (1948), where they are ascribed to the Japan Canning Company.

the military for use as troop supply boats in the forward areas, as coastal freighters in home waters, or as picket boats. By the last year of the war most of the fleet was exposed to Allied air and sea attack and much of it was destroyed. Kimura (1949) notes that in 1942 the number of large bait boats in operation was cut to less than half that of the preceding year, that the number was further decreased in 1943, and he presents no data at all on pole-and-line tuna fishing for the years 1944 to 1946. One sees statements that almost all the large vessels of the Japanese tuna fleet were destroyed by the end of the war (Japan Federation of Tuna Fishery Cooperative Associations, 1951), however, according to the Japanese Fisheries Agency (1955), in 1945 the fleet was down to 33 percent in number of boats and 52 percent in tonnage of the 1939 level. Meanwhile, there had been developments on the west coast of North America that were to be an important factor in stimulating the postwar recovery of the Japanese albacore fishery. In 1937, sizeable landings of albacore were made for the first time in the North Pacific Coast States of Oregon and Washington (Powell and Hildebrand, 1950). The landings in this area grew for several years, reaching a peak of 34 million pounds in 1944 and causing establishment of a number of canneries in the Northwest. The landings then declined sharply and remained at a comparatively low level (10 to 15 million pounds) until 1953, when they dropped to almost nothing (Anderson and Power, 1953). Thus when the Japanese got their live-bait tuna fleet back into full-scale operation after the war, they found an expanded export market for frozen albacore waiting for them.

The recovery of the Japanese tuna fleet in the postwar years was rapid and thorough. Within 2 years after the end of hostilities, the number of tuna boats was apparently greater than it had been in 1940, and there has been an unsteady upward trend in the size of the fleet and a steady increase in the average tonnage of the boats during the 10 years following the war (table 5). Albacore catches have risen to unprecedented heights in the last 4 or 5 years, and the resource shows no signs of failing under the fishing pressure. The serious problems of the fishery are all related to fluctuations, natural and artificial, in the United States demand for Japanese albacore and to the competition between various elements of the Japanese fishing industry for a share in the export trade.

Table 5.—Japanese tuna fleet, by years, 1940 and 1947–55

Year	Number of boats	Total		Average	
		Tonnage	Horsepower	Tonnage	Horsepow
1940	[1] 708	47, 297	94, 122	67	13
1947	956	72, 864	127, 512	76	13
1948	1, 146	94, 230	170, 969	82	14
1949	1, 163	96, 426	181, 707	83	15
1950	1, 100	92, 158	196, 098	84	17
1951	1, 187	101, 471	221, 334	85	18
1952	1, 130	103, 815	227,638	92	20
1953	1, 154	112, 945	249, 439	98	21
1954	1, 263	142, 892	293, 523	113	23
1955	1, 372	176, 026	389, 837	128	28

[1] There were 335 other boats of unknown tonnage.
Source: Katsuo to Maguro, February 1956, Japanese Federation of Tuna Fishing Cooperative Associations.

PHYSICAL SETTING OF THE FISHERY

The Japanese home islands of Honshu, Kyushu, and Shikoku form an arc trending roughly northeastward between 31° N. and 41° N. latitude at 130° E. to 142° E. longitude (fig. 1). A line of small islands and reefs leads south from the southern tip of Kyushu to Okinawa and Formosa, and another chain, the Nampo [Nanpo] Shotō, runs south from central Honshu to the Bonins, the Volcano Islands, and the Marianas. For tuna fishery statistics, the areas south and east of the home islands are divided as follows: Satsunan area, waters west of 130° E., that is, west of Kyushu and including the Ryukyus; Kinan area, waters south of Kyushu, Shikoku, and central Honshu, between 130° E. and 140° E. longitude; Zunan area, east of 140° E. longitude and north to 35° N. latitude, taking in the islands of Nampo Shotō; and Tōhoku or the northeastern area, waters north of 35° N. latitude and east of northern Honshu.[4] Only the Kinan, Zunan, and Tōhok areas contain significant fishin grounds of the albacore summe fishery.

The warm current, Kuroshi flows northeast off the coasts o eastern Kyushu, southern Shikok and central Honshu, turning east ward toward the central Pacific o northeastern Honshu, where i meets the cold current, Oyashi flowing down from the north. Th location of this meeting, and con sequently the extent of the war and cold water areas off the Ja anese islands, shifts north an south with the seasons. The su face albacore schools fished by t live-bait fleet, like the skipjack, a associated with the warm curren and their migration through t area of the fishery coincides wit the northward extension of t Kuroshio in spring and summer.

Fleet Bases

Tuna live-bait boats are regi tered (fig. 1) in all prefectures

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[4] The traditional boundaries of these fishing grounds are slightly different from those of the statistical areas of the same names, whi were laid out on meridians 10° apart. T "nan" in the names of these areas mea south, and the areas are designated by th locations south of the former provinces Satsuma, Kii, and Izu.

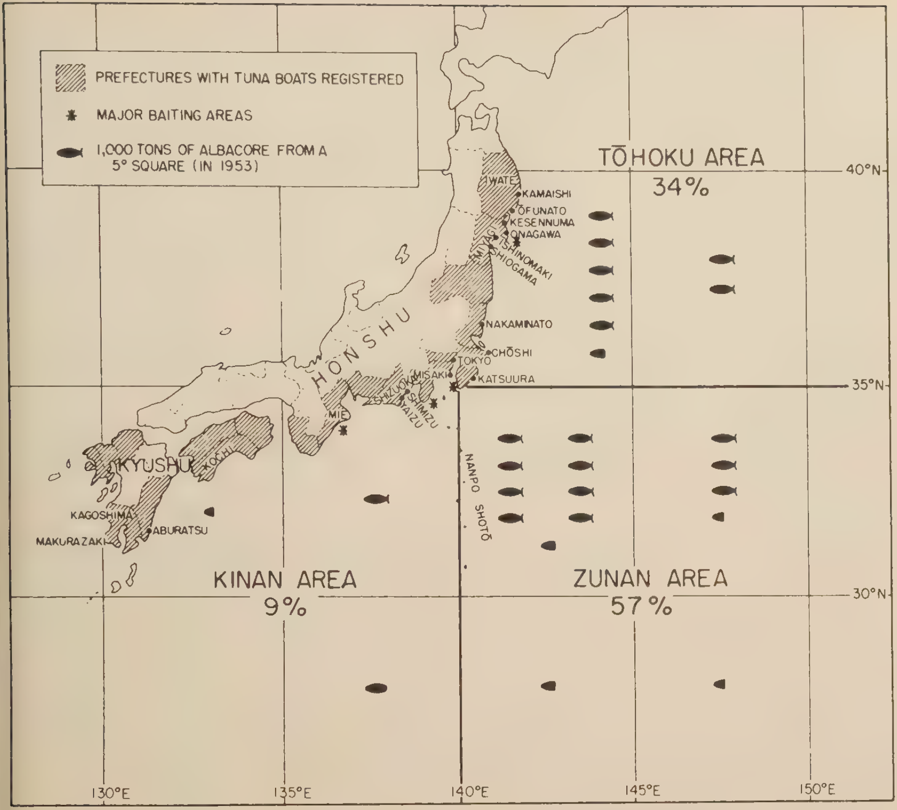

▨ PREFECTURES WITH TUNA BOATS REGISTERED
✱ MAJOR BAITING AREAS
1,000 TONS OF ALBACORE FROM A 5° SQUARE (IN 1953)
TŌHOKU AREA 34%
KINAN AREA 9%
ZUNAN AREA 57%
HONSHU
KYUSHU
KOCHI
IWATE
MIYAGI
KAMAISHI
OFUNATO
KESENNUMA
ONAGAWA
ISHINOMAKI
SHIOGAMA
NAKAMINATO
CHŌSHI
TOKYO
MISAKI
KATSUURA
SHIZUOKA
SHIMIZU
YAIZU
MIE
NANPO SHOTŌ
KAGOSHIMA
ABURATSU
MAKURAZAKI
40°N
35°N
30°N
130°E
135°E
140°E
145°E
150°E

Figure 1.—Location of albacore fishing areas, baiting grounds, and bases. Percentage figures are the portion of the 1953 catch taken in the area. (Based on data prepared by Statistics and Survey Division, Japanese Ministry of Agriculture and Forestry, 1955.)

the Pacific coast of Honshu, except Aomori, the northernmost prefecture, in all four prefectures of Shikoku, and in all but two of the seven prefectures of Kyushu. Table 6 indicates certain peculiarities in the distribution of these boats and their operations. Some prefectures, such as Kochi in Shikoku, have large fleets of small coastal skipjack boats, of less than 20 tons gross, but few of the larger high-seas vessels, which bring in the bulk of the summer albacore catch. Other prefectures, such as Mie, have a considerable number of large boats, which, however, seldom work out of ports in their home prefecture. In 1952, for example, only 5 percent of the catch of the fleet registered in Mie Prefecture was landed in Mie ports. In northern Honshu, Miyagi Prefecture has a sizeable fleet of large boats and important albacore landings, but no small coastal skipjack boats are registered there.

The reasons for these peculiarities of distribution may be found in the historical development and geographical setting of the fishery. Some Japanese authorities

Table 6.—Geographical distribution of registry of tuna live-bait boats and of trips landed, 195

[By tonnage class of vessel]

Prefecture and port	Number of registered boats weighing—		Number of trips landed by vessels weighing—				
	<20 tons	>20 tons	<20 tons	20–50 tons	50–100 tons	>100 tons	>20 tons
Shizuoka	662	176	16, 260	1, 830	1, 260	870	3, 960
Yaizu				350	920	660	1, 930
Shimizu				20	230	190	440
Numazu				880	90	0	970
Ito				340	0	20	360
Ajiro				190	20	0	210
Shimoda				50	0	0	50
Kagoshima	0	54	140	380	1, 100	160	1, 640
Makurazaki				190	660	120	970
Yamakawa				170	420	30	620
Kagoshima				20	20	10	50
Miyagi	0	75	0	0	530	480	1, 010
Kesennuma				0	90	270	360
Onagawa				0	210	90	300
Ishinomaki				0	140	60	200
Shiogama				0	90	60	150
Mie	1, 124	109	14, 241	170	100	90	360
Nakiri				70	60	40	170
Hikimoto				50	20	0	7
Owashi				40	20	0	6
Hamajima				10	0	10	2
Tasoura				0	0	20	2
Yadoura				0	0	20	2
Kanagawa: Misaki	273	10	5, 480	0	220	110	33
Miyazaki	319	49	5, 520	150	60	0	21
Nango				130	0	0	13
Aburatsu				0	40	0	4
Sotonoura				20	20	0	4
Ibaraki	189	53	1, 888	0	140	0	14
Nakaminato				0	100	0	10
Hiraiso				0	30	0	3
Isozaki				0	10	0	1
Chiba	605	3	15, 451	70	20	0	9
Katsuura				70	0	0	7
Chōshi				0	20	0	2
Iwate: Ōfunato	0	7	0	0	30	40	7
Tokyo: Tsukiji	29	12	301	0	30	30	6
Fukushima	118	18	1, 217	0	40	20	6
Ena				0	40	10	5
Onahama				0	40	10	1
Kochi	968	5	48, 095				
Nagasaki	249	0	4, 421				
Ehime	185	0	10, 901				
Wakayama	141	13	1, 571				7
Fukuoka	28	0	952				
Tokushima	19	27	391				31
Saga	5	0	35				
Aichi	0	11	0				

Sources: Annual Report of Catch Statistics for 1953, and Recent Skipjack and Tuna Fishing as Seen in Catch Statistics, 1955. Although both sources are compilations of the Statistics and Survey Division, Japanese Ministry of Agriculture and Forestry, there are numerous discrepancies between their figures.

(Imamura 1953) hold that the Wakayama-Mie area of south central Honshu (known as Kishu) is the cradle of the skipjack fishery and that the techniques spread both north and south along the Pacific coast from that area. Be that as it may, the early centers of the fishery in the days of sails and oars appear to have been generally on promontories extending out toward the fishing grounds in the Kuroshio. Such areas often had poor internal communications, but as long as the vessels and catches were small the local markets could absorb the production. The invention of katsuobushi, or hard-dried skipjack loins (in the 17th century, according to Yamaguchi 1947), supplied a way in which skipjack could be processed anywhere with very simple equipment into an imperishable product that could be shipped by sea to the major population centers. At this stage the small bases scattered along the coast were adequate for the fishery. Then came the trend to larger, powered vessels that required more capital, better port facilities, and larger bait supplies, and that landed fares which no small local market could absorb. With the growth of great urban centers requiring huge supplies of fresh fish, the operations of the fishery became more and more concentrated in a few ports strategically located with respect to the fishing grounds and railroad lines to the major population centers. Meanwhile many of the old skipjack fishing ports declined in importance (Hara 1954). The traditional skills have survived, however, in Kishu and other old skipjack coasts. Many fishermen from these areas serve on vessels registered in other prefectures, while numerous fine boats working out of the great tuna ports carry inscribed on the stern the name of some small cove to which they may return only two or three times a year.

Mie Prefecture, as previously mentioned, is an interesting example of a prefecture with a strong tradition for tuna fishing and a large fleet but without important operating bases. In 1953, the high-seas (more than 20 tons) live-bait boats registered in this prefecture made a total of 1,420 trips, of which only 18 percent were from bases in the home prefecture. For this reason the seasonal movements of the Mie fleet give a particularly clear picture of the general pattern of movement of the fishery.

In February and March of 1953, activity was at a low ebb and consisted of skipjack fishing along the Ryukyu chain from the bases of Makurazaki and Kagoshima in southern Kyushu. April found most of the boats fishing out of home ports in Mie Prefecture, but some were still working from the south Kyushu bases and several had already moved northeastward up the Honshu coast to Yaizu in Shizuoka Prefecture. In May, activity picked up considerably, and although the number of trips based on Makurazaki increased to 40, the real center of operations of the Mie fleet shifted east from the home prefecture to Yaizu, with 100 trips, while 20 cruises were made out of the Kanagawa Prefecture port of

Misaki, still farther to the northeast. In June, the peak month for pole-and-line albacore fishing, the main base for Mie boats was Misaki, followed by Yaizu, and the southern port of Makurazaki showed almost no activity. July found the Mie fleet at the height of its activity for the year, with 410 trips distributed among bases in three areas.

Vessels fishing off northeastern Honshu made 170 trips, divided fairly evenly among the ports of Ōfunato, Kesennuma, Onagawa, Ishinomaki, Shiogama, and Chōshi. Yaizu was still the leading base with 100 trips, which with 40 others from Shizuoka Prefecture ports indicated that quite a few boats were still working off central Honshu. In addition, there were 100 trips out of Mie Prefecture ports by boats fishing in the Kinan area. The total number of trips fell off to 260 in both August and September, with most of the activity concentrated in northeastern Honshu ports, and by October live-bait fishing by Mie boats was nearly at an end, with only 10 trips, all from Yaizu.

The trend toward concentration of landings in a few ports is especially strong in the case of the albacore fishery. Being primarily an export product, the albacore must be landed where canneries or freezing and cold-storage facilities are available. Albacore landings (tables 7 and 8) and the operations of large live-bait boats (table 6) are strongly concentrated at Yaizu and Shimizu in Shizuoka Prefecture, at Misaki in Kanagawa Prefecture, at Tokyo, and in northern Honshu at Kesennuma and Onagawa in Miyagi Prefecture and Nakaminato in Ibaraki Prefecture (fig. 1). The importance of the Shimizu-Yaizu area is partly due to its having been the first place in Japan where tuna were canned in plants set up to pack mandarin oranges, and it is still alternating this activity with tuna canning. There are said to be about 60 plants in this area that can tuna.

Table 7.—Annual albacore landings, by prefecture, 1952–55

[All fishing methods]

Prefecture	Tons landed in—			
	1952	1953	1954	1955
Shizuoka	34, 610	28, 959	25, 902	22, 269
Kanagawa	8, 439	10, 065	11, 666	6, 665
Miyagi	8, 179	4, 675	5, 635	3, 264
Tokyo	6, 574	4, 894	7, 509	5, 345
Ibaraki	2, 308	4, 688	3, 614	4, 451
Chiba	1, 204	712	314	343
Wakayama	1, 154	989	1, 295	1, 047
Kochi	760	579	116	273
Kagoshima	712	372	149	75
Fukushima	542	393	161	211
Mie	422	116	79	240
Iwate	397	269	145	67
Osaka	228	327	397	261
Ehime	137	211	45	169
Aichi	33	33	0	0
Tokushima	25	21	0	0
Nagasaki	12	0	0	12
Aomori	8	4	4	8
Miyazaki	4	4	0	0

Source: Annual Reports of Catch Statistics, Japanese Ministry of Agriculture and Forestry, for the years concerned.

Fishing Grounds

The grounds of the summer fishery for albacore lie, for the most part, in the three major statistical areas that the Japanese call the Kinan, Zunan, and Tōhoku areas, (fig. 1) approximately between 25° N. and 40° N. latitude, 130° E. to 160° E. longitude. The boundaries of these areas vary slightly in different Japanese publications. Apparently the only published analysis of the distribution of albacore

Table 8.—Monthly albacore landings by prefecture, April–August 1953

[All fishing methods]

Region and prefecture	Tons landed in—				
	April	May	June	July	August
Northern:					
Iwate	0	0	54	109	0
Miyagi	79	99	1,456	761	0
Fukushima	0	67	269	29	0
Ibaraki	455	823	1,220	269	0
Central:					
Chiba	12	124	70	21	0
Tokyo	439	186	1,270	199	12
Kanagawa	261	1,353	6,027	505	124
Shizuoka	1,283	3,144	8,499	2,511	8
Aichi	8	17	0	0	0
Mie	17	59	0	0	0
Southern:					
Wakayama	63	25	4	0	0
Tokushima	0	12	4	0	0
Kochi	0	25	105	319	4
Ehime	0	59	33	116	0

Source: Annual Report of Catch Statistics, Statistics and Survey Division, Japanese Ministry of Agriculture and Forestry (1954).

fishing effort and catch within these broad areas is that contained in Recent Skipjack and Tuna Fishing as Seen in Catch Statistics, compiled by the Statistics and Survey Division, Agriculture and Forestry Economics Bureau, Japanese Ministry of Agriculture and Forestry (1955). The report covers only 1953, a year that seems to have presented no conspicuous anomalies, and the data are broken down into squares of 5° of latitude and longitude or areas approximately 300 miles square. The picture thus presented is not one of fine detail, but since it is the best available, it has been made the basis of the following discussion.

The Zunan sea area—roughly the waters south to southeast of Tokyo Bay, and including the Izu Islands and Nampo Shotō—which is second to the Tōhoku or northeastern area in skipjack landings, produced some 14,417 tons of albacore in 1953, or 57 percent of the pole-and-line albacore catch. Within this area the bulk of the catch came from the 5° square on the east side of the Izu Islands (30°–35° N., 140°–145° E.), with 9,690 tons, and from the next block to the eastward (30°–35° N. 145°–150° E.), with 3,613 tons. Next in importance among the major sea areas was the Tōhoku, with 8,671 tons, or 34 percent of the total. Here the block adjacent to the coast at 35°–40° N. had the highest landings, 5,424 tons, followed by the next block to the east, with 2,137 tons. The Kinan sea area, south of western Honshu and east of Kyushu, which slightly surpassed the Zunan area in skipjack landings, was a poor third in albacore, with only 2,327 tons or 9 percent of the catch, over half of it from the 5° block at 30°–35° N., 135°–140° E., in the northeastern corner of this sea area.

It is interesting to note, as an indication of the degree to which the grounds of the summer albacore and skipjack fisheries overlap, that of the 12 statistical blocks (5° squares) from which pole-and-line albacore catches were reported in 1953, 7 had bigger catches of skipjack than of albacore, and there was no block having a large albacore catch without correspondingly large skipjack landings. The most purely albacore ground was the square at 25°–30° N., 145°–150° E., where 74 percent of the catch was albacore. Next highest was the square at 35°–40° N., 155°–160° E., with 67 percent albacore. Only two other blocks—those at 30°–35° N., 140°–150° E.—had more than half of their live-bait tuna catch in albacore, with 58 percent in each case.

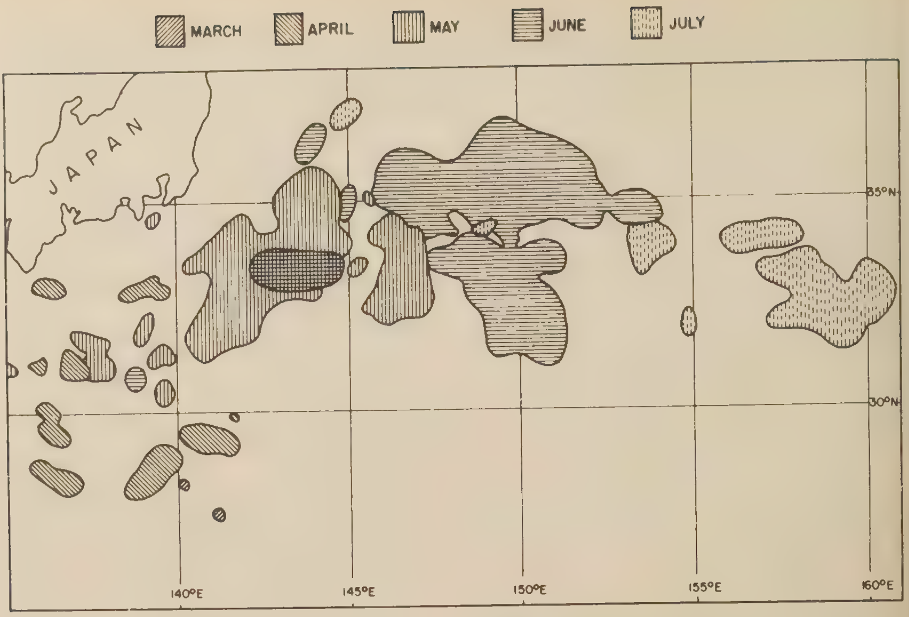


Figure 2.—Simplified composite chart of the distribution of summer albacore fishing grounds in 1953, 1954, and 1956, adapted from Mie Prefecture Fisheries Experiment Station reports for those years. (The north-south extent is exaggerated, particularly at 150° E., since the southernmost grounds appeared only in 1953, when the whole pattern appeared to be pushed to the south.)

The foregoing breakdown in terms of such large areas gives a deceptively diffuse picture of the geography of the albacore grounds. The distribution of the fishing grounds (fig. 2) is focused into a more meaningful, but perhaps oversimplified, outline in charts published in several annual reports of the Mie Prefecture Fisheries Experiment Station (1952, 1955, 1957). For the 3 years 1953, 1954, and 1956 these plots show quite similar distributions of the grounds in the form of a broad arc having its left (western) end anchored in the Kinan sea area near the Nampo Shotō island chain at around 30° N., 140° E., sweeping up northeastward parallel to the south coast of Honshu, and gradually turning to the east along the latitude of Tokyo Bay (about 35° N.). This band of albacore grounds, which appears to average 200 to 300 miles in breadth, reaches farthest north at 36°–37° N. latitude around the longitude of 150° E., and thence drops off to the southeast, ending in the area around 32°–33° N., 160°–165° E. The whole arc is not fished simultaneously, the season beginning in the west and ending in the east. Since the distance of the grounds from port varies from less than 100 miles at the western end to over 1,000 miles at the eastern, there is a progressive withdrawal from the fishery of the smaller boats which return to skipjack fishing as the albacore move offshore.

The three plots on which figure 2 is based also show that during the 6-year period from 1951 to 1956 there was an eastward extension of the albacore grounds from about 155° E. to 165° E. longitude. This undoubtedly reflects the growing proportion of larger vessels in the fleet. Japanese albacore fishermen give as one of their reasons for abandoning the pursuit of the albacore on these easternmost grounds the belief that the schools become more scattered there and harder to find. It may be proving possible to cope with these difficulties more effectively as the number of large boats following the albacore out beyond 1,000 miles increases, for this fleet relies to a high degree on cooperative scouting and radio reporting. Thus the ability of the fleet to keep contact with the schools should be enhanced by the addition of more boats capable of operating on the distant grounds.

Season and Water Temperatures

The normal seasonal pattern of development of the Japanese summer fishery for albacore is for sporadic catches of small numbers of fish to begin in March and continue through much of April along the Izu Islands chain and the Nampo Shotō and in the Kinan area— the albacore being taken at this time by boats operating mainly for skipjack and small bigeye tuna. Sometime between the latter part of April and the end of May the first large catches are made and the fleet begins to concentrate in earnest on albacore fishing. Kimura (1942) recorded the dates on which daily catches of around 1,000 fish per boat began to be made in the period of 1936–39 as ranging from April 18 to May 29, the locations being 120 to 300 miles southeast of Tokyo Bay. Reports for more recent years (Mie Prefecture Fisheries Experiment Station, 1952, 1955, 1957) show a similar early-season development. By the middle of June (rarely in the latter part of May) the landings rise steeply to their peak for the season (table 9 and fig. 3). Simultaneously, skipjack landings drop, indicating a real shift in fishing effort (fig. 4). At this time, fishing is centered well offshore around 150° E. and at its farthest north for the season, extending as far as 37° N. Albacore are still being fished, however, between this ground and the coast, often on two or three distinct grounds at different longitudes. In some years a ground may develop close in to the coast of northeastern Honshu at a slightly higher latitude than that reached by the offshore grounds, and persist into early July. In July the offshore fishing activity shifts east to 160°–165° E. and south to 33°–34° N., the fishing nearer the coast south of 35° N. fades out, landings decline rapidly, and by the end of July the albacore season is virtually over and the fleet has gone back to skipjack fishing. It seems likely that the steepness with which the catch curve rises and declines does not really represent the way in which the albacore become available in the area of the fishery, but reflects the fact that most of the fleet fishes skipjack except during the brief period when albacore are at their highest level of abundance.

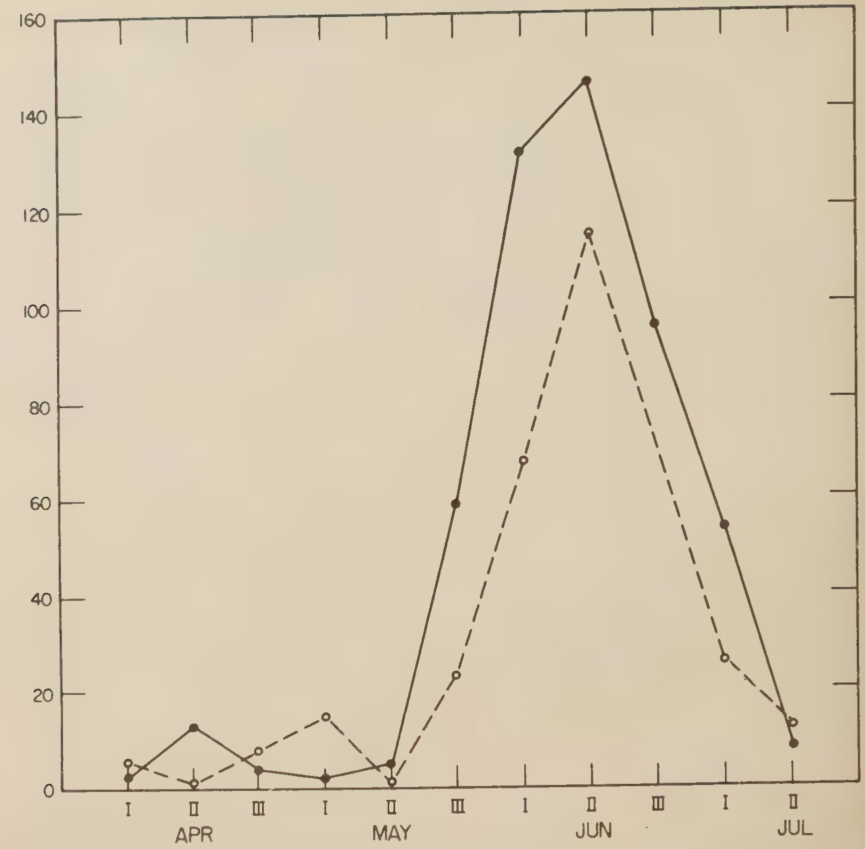


Figure 3.—Trends of albacore landings by 10-day periods (Roman numerals), April to July, 1952 (solid line) and 1953 (broken line), at the ports of Shimizu and Yaizu. Vertical scale is in 10 thousands of kan, equal to slightly more than 41 tons. (From Tokai University, 1954.)

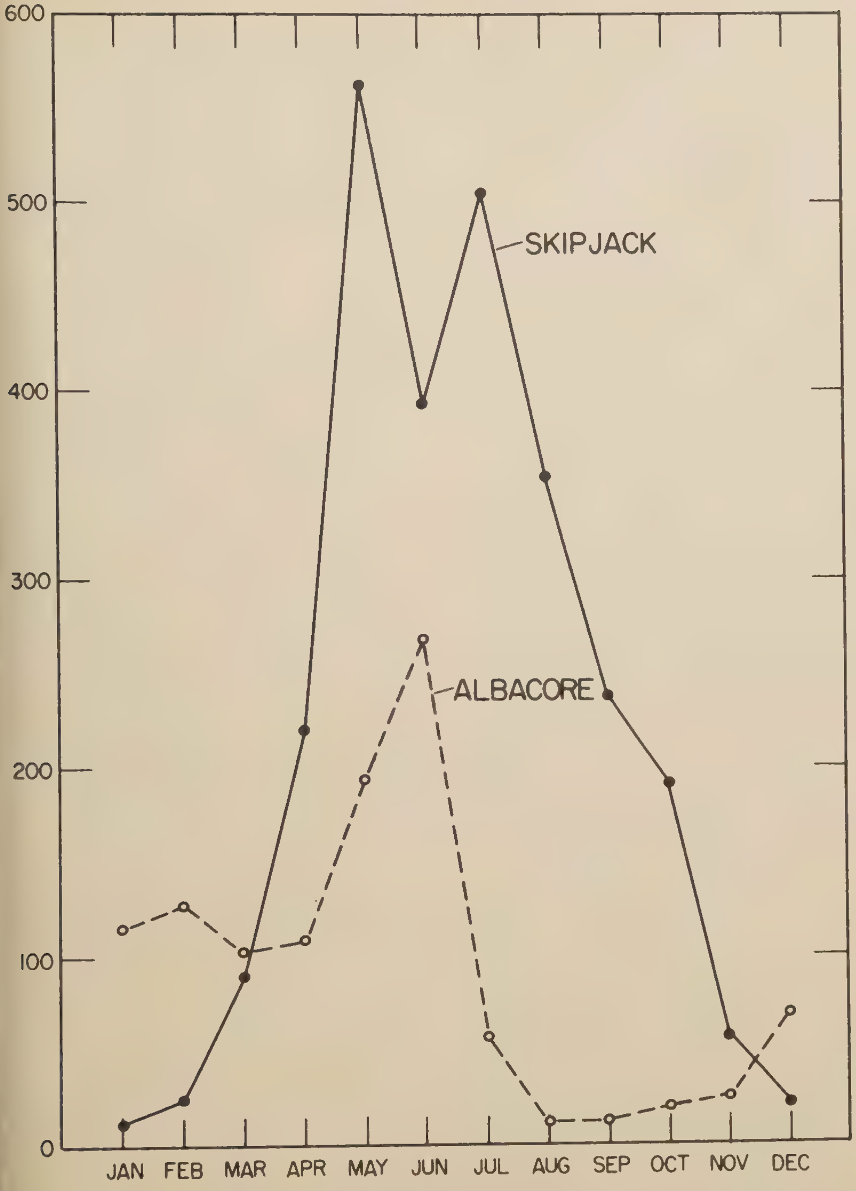
Table 9.—Total Japanese albacore landings, by months, April to August, 1947-55

[All fishing methods]

Month	Tons landed in—					
	1947–50 (average)	1951	1952	1953	1954	1955
April	992	1, 333	2, 871	2, 697	3, 827	4, 70
May	1, 372	3, 735	4, 414	6, 023	3, 661	7, 88
June	4, 885	9, 292	36, 803	24, 098	9, 954	10, 92
July	1, 393	2, 725	6, 565	4, 857	10, 549	2, 44
August	629	64	120	157	1, 804	31

Sources: Figures for 1947 to 1951, from Katsuo to Maguro, Nos. 26 and 28 (Japan Federation of Tuna Fishery Cooperative Associations, 1952); figures for 1952 to 1955, from annual reports of catch statistics, Japanese Ministry of Agriculture and Forestry.

The Japanese believe that the rate at which these developments occur and the details of albacore availability over this expanse of fishing grounds and throughout this season of approximately 3 months are controlled by the way in which the seasonal warming of



gure 4.—Trends of monthly landings of skipjack and albacore in 1955. Vertical scale is in 10 thousands of kan, equal to slightly more than 41 tons. Similar drops in skipjack landings appeared in June in 1952, 1953, and 1954. (From annual reports of catch statistics, Japanese Ministry of Agriculture and Forestry.)

e area by the Kuroshio pro-resses. This belief is based on e assumption that water temper-ture is the main factor controlling e development of good albacore fishing. The range of optimum water temperature for albacore fishing in May and June (surface-water temperatures at which the largest numbers of albacore were taken) is given as 64°–70° F., with the catch maximum at about 68° F., by Uda and Tokunaga (1937), while a report of the Miyagi Prefecture Fisheries Experiment Station (Sasaki 1939) states that over a number of years 50 to 80 percent of the summer albacore catch was taken at 68°–70° F., the next most favorable temperatures being 71°–72° F., 66°–67° F., and 73°–74° F., in that order. In Japan, these surface temperatures are given great weight in scouting for albacore and in reporting and forecasting the fishing situation. The way in which the pattern of surface temperature distribution develops is thought to affect the success of a summer albacore season mainly through its effect on the early part of the season in the western grounds. In some years the strength of the warm Kuroshio pushes northward in such a way that isolated masses of water of suitable temperature lie close in to the southeast coast of Honshu until the end of May or even later. Not only is this condition thought to favor successful fishing by concentrating the schools of albacore, it also prolongs the period during which the smaller, short-range skipjack boats can effectively fish albacore (Inoue 1955). In years when the Kuroshio comes to full strength unusually early, as in 1954 (Tokai University, 1954), these isolated cool-water areas either do not develop or are shortlived, the schools move offshore to the northeastward more rapidly, and fishing is poor for the coastal fleet. The effect of such fluctuations in hydrographic conditions on the overal success of the season is probabl decreasing as the role of the large boats operating on the more distan grounds becomes more importan

FLEET AND OPERATING REGIME

Japanese live-bait tuna boat and their fishing gear have bee described and figured by severa authors in recent years (Cleave and Shimada, 1950; Shapir 1948; Japanese Fisheries Agenc 1955) and so will be treated onl briefly here. The most conspicu ous characteristics of these craf are the long, high bowsprit bear ing prolongations of the fishin racks, the racks extending alon one or both sides of the vessel an around the stern, only about 1 foo below the high gunwale, and th spray-system pipes, with closel spaced nozzles, paralleling th racks. The superstructure is a abaft the beam, and the long ope welldeck has 9 or 12 hatche Those hatches along the sides lea to the iced fish holds and thos along the midline open into th live wells. Pump circulation fo bait wells has not yet caught on i Japan, and the practice of circu lating the water through simp openings in the vessel's bottom almost universal in Japanese ba boats. Most of the boats of les than 130 tons gross are of woode construction; all of the larger shi are steel.

The strength of the fleet en gaged in the summer fishery fo albacore is not exactly determinab rom published statistics, which resent ill-defined and irreconcilble figures (tables 5 and 10). igures similar to those in table 5 re presented in Japanese Fisheres (Japanese Fisheries Agency, 955), where they are identified as licensed skipjack and tuna [i.e., ive-bait and longline] fishing oats." Probably they include nly the larger boats and perhaps nly those whose owners belong to ie Japanese Federation of Tuna ishing Cooperative Associations. he figures on live-bait boat rength for 1953, as given in table), are confirmed in the publicaon, Recent Skipjack and Tuna ishing as Seen in Catch Statistics Japanese Ministry of Agriculture nd Forestry, 1955). Since this ble has been compiled from the apanese Government's official anual fisheries statistics report, it hould perhaps be accepted as the est information available.

ble 10.—Number of powered skipjack pole-and-line vessels, by gross tonnage classes, 1953–55

Year	Number weighing—				
	<20 T.	20–50 T.	50–100 T.	100–200 T.	>200 T.
3	4, 101	148	296	178	0
4	4, 804	180	303	227	4
5	4, 646	162	260	279	14

NOTE.—As late as 1955 the annual statistical report wed 508 nonpowered vessels engaged in tuna pole-l-line fishing.

ource: Annual reports of catch statistics, Japanese nistry of Agriculture and Forestry.

It appears from tables 5 and 10 at by 1948 the Japanese tuna fleet id already surpassed its prewar rength and that since that time the et has continued to expand, at ast to 1954. It is also clear that the postwar years have seen a steady increase in the average size of Japanese tuna boats. There is a hint of a turning point in 1954, with the number of boats in the smaller size classes showing a decline in 1955, while the number in the larger tonnage classes continued to grow (table 10). It may be noted in passing that the increase in size of live-bait boats has not been as striking as in that of tuna longline boats, which are commonly being built over 500 tons and, exceptionally, to 1,000 tons gross. For live-bait boats, under present operating and marketing conditions, the practical limit seems to be somewhere in the vicinity of 300 to 320 tons. This is because the Japanese live-bait tuna fishery is primarily a skipjack fishery. The skipjack grounds are largely within the range of the smaller vessels, the market demands iced rather than frozen skipjack, and iced skipjack cannot be landed in good condition from cruises of the length necessary to load up a larger boat. Boats in the 300-ton class have an advantage when it comes to pursuing the albacore schools east to 165° E., but they are probably not economical for skipjack fishing. In fact, many of the boats over 150 tons now turn to South Seas longlining rather than to skipjack fishing after the albacore season ends.

The thousands of coastal (i.e., less than 20 tons gross) live-bait boats that swarm around the Japanese coasts make a surprisingly small contribution to the albacore catch, or for that matter, to the skipjack landings. The only species in which they lead is frigate mackerel. In 1953, for example, when 4,917 of these small vessels were operating as compared with 622 boats of more than 20 tons, they landed only 736 tons of albacore, or about 2 percent of the total pole-and-line catch of this species. As noted earlier (p. 3), albacore made up only about 4 percent of the catch of the coastal boats in 1953 as compared with 33 percent of that of the larger boats. Albacore occupied an even bigger share, 36 percent, of the high-seas catch in 1952, but earlier, in the period of 1947–49, the average was only 8 percent, perhaps in part because of the smaller number of big boats fishing then.

A live-bait boat of around 200 tons gross, the class which appears to be the backbone of the albacore summer fishery, will make from 3 to 5 trips in a season primarily to fish for albacore. On nearly all of these cruises some skipjack are taken, and small amounts of albacore may also be caught on earlier or later trips that have skipjack as their primary object. Length of trips averages about 5 days for 20- to 50-ton, 10 days for 50- to 100-ton, and 12 days for 100- to 200-ton boats, of which 2, 4, and 5 days, respectively, are spent in actual fishing (Japanese Ministry of Agriculture and Forestry, 1955).

More detailed information is available concerning operations in several recent years from the 196-ton *Jini Maru*, which, although it was the fisheries guidance vessel of Mie Prefecture, worked very much like an ordinary commercial craft (Mie Prefecture Fisheries Experiment Station, 1952, 1953, 1955, a
1957). In the 4 years 1951, 19
1954, and 1955, this ship made fr
7 to 14 live-bait fishing cruises
season, the earliest cruise beginni
April 11 and the latest ending
tober 5. Cruises were from 6 to
days in duration, averaging ab
12 days. In 1951, albacore w
taken on the first three trips (M
22–July 2) but formed the grea
part of the catch only on the seco
cruise (June 8–19). In 1952, s
stantial quantities of albacore w
taken on all trips from the seco
to the fifth (May 21–July 12).
1954, some albacore were caught
the first and second cruises and
the fifth through the seventh crui
of the 11 cruises made that seas
but they did not form the ma
part of the catch on any trip.
1955, when 14 trips were ma
albacore figured in the catch on t
third through the sixth crui
(May 11–July 6), predominati
on the fourth and fifth (May 2
June 23). The *Jini Maru*'s reco
also show small numbers of bige
tuna taken, usually in associati
with skipjack, on quite a few of
cruises.

Few data have been found on t
average size of the fares brought
from albacore cruises. The analy
of the 1953 figures by the Statist
and Survey Division, Japan
Ministry of Agriculture and For
try (1955), gives a figure of o
642 pounds as the average albac
landings per trip for the high-s
fleet, but since this is appare
averaged out over the whole sk
jack season, it is not a very me
ingful statistic. Perhaps more

vant is the figure given in the same ource for the average albacore atch per trip in the 5° block at 30°–35° N., 140°–145° E., the statistical rea having the highest total alba-ore catch in 1953 and in which al-acore made up 58 percent of the ole-and-line catch. Here the av-rage was 17,350 pounds per trip. For the *Jini Maru*, in 1951 albacore atches ranged from 710 to 91,019 ounds, averaging 38,843 pounds, nd in 1952, the range was 57,000 o 112,644 pounds, with an average f 89,949 pounds (Mie Prefecture isheries Experiment Station, 1952, 953).

Japanese live-bait boats are sually unloaded, fueled, iced, and eady for sea within 24, or at most 8, hours after returning to port. he usual practice is to sail at an our that will bring the boat to the aiting station early in the morning. ince bait is purchased out of hold-g nets, baiting generally takes nly an hour or two, however, it is uite commonly necessary to visit vo or more stations in order to get ough bait for a trip. The dura-on of cruises seems to be deter-ined in most cases by the length of me the bait supply lasts.

ishing Method

Scouting for albacore off Japan summer is carried on by radio telligence, visual observation, and olling, in that order of descending portance. Each ship carries a rofessional radioman whose prin-pal duty is to pick up and relay dio reports on the fishing situa-on. The intensity of this ex-ange of information results in a high degree of concentration of vessels on the grounds, it being not unusual to have 25 or 30 boats in sight at one time. Large numbers of lookouts keep watch from dawn to dusk, looking for bird flocks and floating timbers, and also keeping a sharp eye on the activity of other boats in the vicinity. Trolling lines, usually two, are dragged at all times, but are relied on principally for a final evaluation of other signs of fish. Competition among vessels appears to be unfettered by any notions of courtesy or even of caution, and when a boat is on fish, others in the vicinity will often maneuver recklessly close and attempt to steal the school.

Albacore fishing is done with two-pole rigs, thus cutting down the number of hooks to half that used when working on skipjack. Since the average numbers of fishermen are 29 on 20- to 50-ton boats, 45 on 50- to 100-ton boats, and 54 in the 100- to 200-ton class, this still leaves fishing power at a rather high level. The use of two-pole gear for fish that usually do not go much over 25 pounds is necessitated by the height of the racks off the water. The fishermen are customarily disposed along the port side and around the bow and stern, with the best fishermen on the bowsprit where the lift is highest, the old-timers at the stern where it is lowest, and the green hands amidships where the fish bite slowest. The favored lure for albacore is a squid with a lead head, polished cowhorn body, and a chicken-feather tail sheathed in cat skin. Bait is chummed at the stern, amidships, and forward from small tanks which are kept supplied by boys carrying buckets of bait from the main baitwells. The spray system is turned on as soon as fish appear close to the ship and continues to play as long as fishing continues. The jets of water ruffle the surface of the sea and perhaps excite the tuna, and also carry the fishermen's lines away from the side.

The schools of albacore encountered off Japan appear to be generally small, perhaps partly because of the intensity with which they are harried and broken up by concentrated fleet action. The usual pattern of fishing is therefore one of taking a few fish from each of a large number of schools. For example, on two cruises of the *Jini Maru* in June 1956 the number of albacore schools fished per day ranged up to 10 and averaged 3 to 3½. The number of albacore taken from a school varied from 4 to 647, averaging 184 on one trip and 156 on the other. An excerpt from this vessel's fishing log for May 31, 1952, will give some idea of what this fishing is like (and also shows the emphasis given to water-temperature measurement):

> Began searching at 0425, heading east. Albacore school at 0623, took 200 fish. Water temperature 70.3° F. At 0740, at 35°32′ N., 164°48′ E., water temperature 67.6° F., small school of albacore, took 49. At 0920, same, took 59, water temperature 68.1° F. At 1050, same, took 140 fish, water temperature 68.1° F. At 1115 a large school of albacore, bit well, took 830, water temperature 68.1° F. At 1310 a small school, took 15 fish, water temperature 68.5° F. At 1335, same, took 173 fish, water temperature 68.4° F. At 1413, same, took 33 fish, water tempe
> ture 70.7° F. Between 1500 and 1
> fished albacore 3 times, took 540, wa
> temperature 68.3° F. Fished sm
> schools of albacore twice between t
> and 1700, took 70, water temperat
> 68.4° F. Ran out of bait at 1740
> headed for port.

Bait

As noted in earlier remarks
the short turn-around time of Ja
anese live-bait boats, the bait us
in the albacore summer fishery
not caught by the tuna fisherm
but is purchased from bait deale
This system has the obvious adv
tage of saving fishing time, a
also, a point that the Japanese tu
fishermen consider important,
tuna boats are usually supplied w
"tame" bait which has been h
for some time and thus avoid
heavy initial mortality often
perienced with freshly caught b
The baitfish are sardine and
chovy taken by various metho
In the only two examples
which published information
been found (Mie Prefecture Fi
eries Experiment Station, 19
the nearly 50,000 buckets of b
sold at the Kamogawa bait
ground in Chiba Prefecture in 19
and the nearly 20,000 buckets de
ered to tuna boats at Kaigata
Kagoshima Prefecture in the sa
year were almost all anchovy.
the former place the bait was ta
in the daytime with seines, while
the latter it was attracted to a li
and captured by lift net at nig

Bait is held on the bait
grounds in koari, bag-shaped n
held afloat on octagonal woo
frames and anchored in water d

enough that the tuna boats can come alongside them. A similar net and demounted frame is carried aboard the tuna boat for the holding of any bait that is left over when the vessel comes into port, as the primitive circulation system will not keep bait alive in the wells of a moored boat. The bait is passed carefully and rapidly from the koari to the bait wells of the fishing boat in buckets, and since the bucket is the unit by which the bait is sold, a careful tally is kept by representatives of both buyer and seller.

The cost of bait is said to account for about 30 percent of the trip expenses of a tuna boat (Mie Prefecture Fisheries Experiment Station, 1952). A bucket (3.2 gallons) of bait, estimated to contain 15 to 16 pounds of fish, has sold in recent years for 1,000 to 2,000 yen, about \$2.50 to \$5.50,[5] and a boat of around 200 tons gross will use on the average about 250 buckets each trip. An additional expense in connection with bait is the necessity of employing one or two bait buyers, who travel up and down the coast making arrangements to ensure that supplies of suitable baitfish will be reserved for the boat when and where needed.

Major baiting areas are in Kagoshima Bay in southern Kyushu, around the Izu Peninsula in Shizuoka Prefecture, along the Miura Peninsula near the port of Misaki, on both the Tokyo Bay and Pacific coasts of Chiba Prefecture, and in Miyagi Prefecture in the northeast. Ideally, the baiting ground is a sheltered bay or cove where the koari can be safely anchored, close to a good fishing ground for anchovy and sardine, and not too far from a major tuna landing port. In actuality, it is often necessary for a vessel landing its catch at Shimizu, for example, to run all the way up to the Tokyo Bay area to take on its bait for the next trip, and at the peak of the season, when there is strong competition for the available bait, a tuna boat often has to visit several baiting grounds to get together enough bait for a trip. There is some evidence of a tendency for the price of bait to be higher at the northeastern baiting grounds than in central and southwestern Japan.

The tuna-bait fishery, although not well documented, is evidently an important business. Trade papers (Nippon Suisan Shimbun, July 26 and August 16, 1957) have reported estimates that about 1,900 vessels are served by members of the commercial bait dealers association and that the annual value of this business is over \$4,000,000. One major baiting ground alone, that of Tateyama on the Chiba Prefecture shore of Tokyo Bay, is reported to gross more than \$800,000 annually.

Ice

As the fleet is primarily engaged in fishing skipjack for a domestic market that, by and large, will not accept frozen fish, the boats are equipped to preserve their catch in ice or, more exactly, in ice water. Such mechanical refrigeration equipment as is found on bait boats is intended only to cut down ice loss when the vessels engage in longlining during the off season and, therefore, is of small capacity. Block ice is loaded, an average of around 40 tons per cruise for a 200-ton boat, at $5 to $6 a ton, and is broken up with hand tools as needed for cooling the water in the fish holds.

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[5] According to a newspaper report (Nippon Suisan Shimbun, January 31, 1958), bait dealers and boat owners provisionally agreed on a price of 700 yen per bucket for bait in the 1958 season.

SIZE OF FISH

A number of reports have been published which deal with the size composition of the pole-and-line albacore catch of the summer season. Among these are the reports of Uno (1936a, 1936b) and Uda and Tokunaga (1937), based on samples from the 1935 and 1936 seasons; Aikawa and Kato (1938) and Tauchi (1940), who present data for 1936 and 1937; and Suda (1955, 1956), who covers data for the period 1948–54. The Nankai Regional Fisheries Research Laboratory (1951) has published length frequencies of large samples from 4 catches landed in 1950 and 53 catches landed in 1951. Two annual reports of the Mie Prefecture Fisheries Experiment Station give, in one case (1953), raw length and weight data for small samples (5 to 20 fish) from about 50 individual schools, and in the other (1957), the length-frequency distributions for similar samples. The earlier of these two reports also presents a brief discussion of the geographical distribution of schools of albacore of different sizes and a
rough length-weight curve. T
earlier workers cited here we
more concerned with the age co
position of the catch (basing the
estimates on Aikawa's readings
vertebral annuli) than with the si
composition as such, but Suda a
tempted to identify length mod
in successive years and to trace t
fluctuations in abundance of t
various size groups in the cat
from year to year.

The facts presented in these r
ports can be practically su
marized as follows. The albac
taken on pole-and-line are co
prised within a range of 50 to 1
cm. (about 6½ to 47 pounds) wi
rare exceptions; Suda (1955) sa
pled one catch of 30- to 37-cm. fi
in 1951. This size range is m
limited on both ends than is that
the winter longline catch in the sa
region and, in fact, the bulk of t
summer catch lies in most years b
tween 60 and 90 cm. (about 11
35 pounds), usually with a stro
mode in the vicinity of 80 cm. (
pounds). In 1935, according to U
(1936a), more than 90 percent of t
fish were between 19 and 31 poun
with the mean for this group at
pounds. In 1936, according
Tauchi (1940), about 46 percent
the catch was between 20 and
pounds in weight, and in 1937 ab
30 percent fell between 19 and
pounds. In a more recent examp
the data from the 1956 operations
the Mie Prefecture fishery guida
vessel *Jini Maru*, the range of a
erage weight in 51 schools samp
was from 14½ to 31 pounds, w
the averages for 34 of the scho
falling between 20 and 23 poun

Suda (1955), studying data for 1951 to 1954, claimed to find from three to five size groups in each year's catch and concluded that the groups above 70 cm. (about 17 pounds) appear consistently from year to year, whereas there is more variation in the availability of the groups of smaller fish.

In the Japanese trade the size of fish is discussed in terms of "kan," a unit of slightly more than 8 pounds. Albacore under 3 kan (about 25 pounds) are called small and those over that weight, large. Published information does not give any clear picture of geographical or seasonal differences in the distribution of fish of different sizes, although it is commonly said that more small fish are taken on the grounds closer to the coast. Mie Prefecture data for the 1952 season show that 97.6 percent of the albacore from the Kinan area and the west side of the Izu chain (west of 140° E.) were large, while of the fish taken east of 140° E., 69.4 percent were small; however, the fact that the main mode in the overall size composition shifts around the 3-kan dividing line can make the proportions of large and small fish differ sharply from area to area and year to year. Thus in 1951, 67.7 percent of the schools were large fish, but in 1952, 78.0 percent were small (Mie Prefecture Fisheries Experiment Station, 1952, 1953).

Practically, the size characteristics of the albacore taken in the Japanese summer fishery can be summarized as quite uniform, large enough to give good recovery in processing, but not so large as to have much "green" or offcolor flesh—all in all, a highly desirable raw material for white-meat tuna packers.

MARKETING AND UTILIZATION

It is inappropriate in a paper that purports only to describe one segment of the Japanese albacore fisheries, which in turn are only one part of the Japanese tuna-fishing industry, to attempt a complete account of the domestic and foreign utilization of Japan's tuna production. Unfortunately, the data necessary to separate the trade in summer-caught albacore from that in winter- and mothership longline-caught albacore are not available. The following paragraphs, therefore, aim only to give a general idea of what happens to the summer albacore catch and of its commercial significance.

When the albacore are landed, they are immediately laid out on the floors of auction sheds on the quay in lots according to size and condition and are bid in by representatives of freezers, canners, and fresh-fish dealers. Prices vary widely, depending on the suitability of the fish for export or other uses, and fluctuate from day to day according to supply and demand, the latter reflecting in a large degree the exporters' assessment of the United States market. The spread between the high and the low offers at a single port in any week is often as much as $100 per ton, and the variation of weekly average prices within a season may be of the same order. In the early part of the

1956 season, for example, the ex-vessel price averaged around $300, but much of the fish bought at this high price level apparently had to be sold at a loss, and the next year the chastened buyers started out offering only $150–$200 a ton. These sharp ups-and-downs are distressing to the Japanese fishermen, particularly as the natural pattern is for the price to be high when they are not catching much fish and for it to fall about the time they come into port with a full load. The concentration of the fleet on the fishing grounds described earlier often means that when one boat loads up, all load up, and then something like a race for the market often develops.

It is interesting to note that in recent years there have been increasing demands for stabilization of albacore prices by season contracts between boat operators and buyers at the same time that some elements of the United States tuna fleet have been moving toward abandonment of the contract system in favor of auctioning their fish. A basic difficulty of the Japanese albacore trade is that although the demand for the product is greatly affected by the success of the United States fishery in the same year, the season in Japan is nearly over by the time the American season gets into full swing. The result is that the Japanese processors must buy their stock before they are in a good position to estimate what the demand for it may be. It has been suggested that if a method could be devised to forecast during the spring the success of the American albacore fishery, it would be o invaluable help to Japanese fishermen and traders in planning thei operations (Inoue 1957).

Assuming that skipjack continu to be fully available to the fleet during the summer albacore season, i would seem that a price differentia in favor of albacore would be th most obvious reason for any diversion of fishing effort from skipjac to albacore. Of course, other factors suggest themselves, such as differences in the distance to th grounds where each species is mos abundant, the possibility of making a load faster with albacore, whic weigh three to four times as muc as skipjack, and so forth. In general there does seem to be a clear-cut price advantage to albacore, although the great variability of th ex-vessel prices of both species appears often to obscure or even reverse this relation. For example the *Jini Maru* in 1951 on cruise from which both species wer landed received on the average $3 more per ton for albacore than fo skipjack, but similar data for tha vessel's 1952 operations show a $1 a ton advantage to skipjack. Market reports published in the Japanese trade press showed in 195 high albacore prices running generally about $100 more per to than the high skipjack price on an given day at any particular port but in the 1957 season this differential was generally much less an was often reversed. Of course, th high skipjack price at any day' auction may represent only a fe choice fish bid in for the fresh-fis trade, and it is noted that the lo id for skipjack is almost always ar below the lowest price offered or albacore.

The albacore is so associated with he export trade in the minds of the Japanese that when asked what use s made of this fish in Japan, they will often state that it is all exported. It is obvious that not all of he albacore landed in Japan can meet the quality standards for export, nor can the world's markets absorb all of the albacore that the Japanese catch in a good year. The figures in table 11, which are drawn from a variety of sources, not all of high reliability, indicate that in some recent years albacore exports have amounted to little more than two-thirds of the catch. In 1955, on the other hand, apparently more albacore was exported than was landed. These difficulties of comparison arise from the fact that export statistics are often not presented on a calendar-year basis and also because frozen and canned albacore may be produced in one year and exported in the next. It appears, however, that over the whole period of 1950–56 a considerable part of Japan's albacore catch, perhaps as much as one-sixth, was consumed domestically. This consumption was in the form of fresh or smoked fish, canned tuna flakes flavored to the Japanese taste, or as one of the ingredients in the increasingly popular fish sausage. Production of canned and frozen fish for export remains, however, the basic objective of the Japanese albacore fishery, and the fact that a certain percentage of the catch is consumed in Japan is largely accidental.

able 11.—Japanese albacore production and exports, with comparative data on other tuna exports, 1950–56

Year	Catch (tons)	Exports				
		Frozen		Canned		Raw material equivalent of canned albacore (tons)
		Albacore (tons)	Other tuna (tons)	Albacore (cases)	Other tuna (cases)	
50	32,628	7,329	2,946	665,319	862,057	13,306
51	32,999	15,999	2,500	403,730	315,390	8,075
52	65,788	21,628	3,890	849,991	234,089	17,000
53	56,985	32,783	13,091	900,000	395,004	18,000
54	57,145	30,543	33,102	792,000	957,374	15,840
55	44,724	33,118	31,821	1,062,597	955,915	21,452
56	64,675	22,012	33,393	1,233,383	1,480,681	24,667

NOTE.—The export figures were adapted from a number of sources: Anderson et al., 1953, Survey of the Domes- Tuna Industry, Special Scientific Report: Fisheries No. 104; Japanese Federation of Tuna Fishery Coopera- e Associations, Katsuo to Maguro, February 1956; Fishing Industry Weekly No. 171; and weekly newsletters the Tuna Research Foundation Division, California Fish Canners Association. The accuracy of the figures thought to be of a low order.

Some figures from a Japanese fisheries yearbook (Suisan Nenkan, 1954 ed.), together with tables 4 and 11, give a general idea of the importance of albacore in Japan's export trade. Before the war (1933–35) fishery products made up about 3 percent of the value of Japan's exports, but this figure rose to 4.5 percent in the postwar years of 1950–52. In the period of 1933–35, tuna products made up only about 11 percent of Japan's fishery exports, as compared with nearly 33 percent in 1950–52. For the prewar period, 64 percent of the tuna exports, which were mostly canned fish, went to the United States, a figure which increased to 80 percent or better after the war. The proportion of frozen fish in Japan's tuna export to this country—only about 25 percent in 1937—grew to about half of the total exports in 1952, and the bulk of this was albacore. Before the war exports were almost entirely albacore, but in the postwar period yellowfin and skipjack light-meat tuna products have gradually come to make up a larger share of the total (table 11). The concentrated reliance of Japan's tuna export business on the United States market since the war has been a source of worry to Japanese tuna producers, for it lays them open to disastrous consequences if production and price trends, or increased tariffs, should hinder their access to the American market. In recent years they have tried to develop export markets elsewhere with some success, and one recent estimate is that more than 20 percent of Japan's canned tuna exports, most of it albacore, now goes to countries other than the United States (American Tunaboat Association, in correspondence).

The export of canned and frozen albacore from Japan, like that of other species of tuna, is subject to rather strict control through a system of quotas, floor prices, and joint sales arrangements set by industry associations acting und the aegis of the Japanese Gove ment. This system has undergo numerous adaptations in rece years and appears to be developi in the direction of a more conce trated channeling of exports a stricter regulation extending fu ther down toward the primary pr ducer. The basic policy behind t system seems to be to assure Jap of the biggest share possible of t world tuna market while at t same time preventing cutthro competition among the elements the Japanese industry, with a tendant price cutting that mig lead to accusations of dumpi and stimulate the raising of tar barriers abroad against Japan tuna.

SUMMARY

The world's greatest single fis ery for albacore, traditionally t choicest and highest-priced tu for canning, is carried on by t Japanese during the spring a early summer in the northweste Pacific. The fishery explo schools of 15- to 25-pound fis which migrate rapidly northea ward parallel to the coasts southern Japan and then turn the eastward along the latitude central Honshu. The season short, from May to July, with peak in June. The fish are tak on pole-and-line, using live-ba chum, and the techniques a equipment are essentially th that are used for fishing skipja Several thousand wooden and st vessels, ranging in gross tonna from less than 20 tons to more th

00, contribute to the landing, but he bulk of the catch is made by a ew hundred of the larger boats, nainly because the principal albaore grounds lie more than 100 niles off the Japanese coast. Alhough boats from all areas of the Japanese Pacific coast participate n the fishery, landings are highly oncentrated in a few ports of centra Honshu, especially in Shizuoka Prefecture.

The fishery has grown up within he past 35 years in response to the lemand of the American market or white-meat tuna, and it is ssentially aimed at production for xport, either as canned or as fresh rozen albacore, to American caneries. From the Japanese point f view this spring albacore fishry is ancillary to the ancient and nuch larger skipjack fishery, out f which it developed and with which it is still inseparably involved. No part of the fleet engaged in the fishery, nor any of the facilities such as baiting grounds and landing places which serve the fleet, is dependent wholly on the albacore fishery or would cease operation if the albacore export trade were cut off. On the other hand, the prosperity and the rapid growth of the Japanese live-bait tuna fleet in recent years have been due in large part to the good market for albacore, and the export of albacore products has contributed more dollars to Japan's economy than any other fishery product. Fishing activity and landings have been maintained at unprecedentedly high levels during the past half decade, and barring a decline in the availability of albacore in the waters off Japan, it seems likely that this fishery will continue to thrive as long as foreign markets continue to take its products.

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A NOTE ON A STABILIZED STARCH INDICATOR FOR USE IN IODOMETRIC AND IODIMETRIC DETERMINATIONS

The problem of preventing biotic hydrolysis of aqueous starch indicators has stimulated innumerable searches for preservatives capable of sustained anti-biotic effect. Walton (1928) has listed abstracts of twenty-three methods purporting to prevent hydrolysis for periods ranging from two months to three years. A more recent and widely-used method is that of Hillebrand and Lundell described by Pierce and Haenisch (1948 p. 237). The method uses 1 g of boric acid per 100 ml of indicator solution.

At this laboratory we have tried several of the recommended methods with varying degrees of success and obtained the most favorable results with a modification of the method described by Hillebrand and Lundell (Pierce and Haenisch 1948). We have increased the starch concentration to 5% and have protected the stock bottle and the dispensing bottle from light. Under these conditions, hydrolysis was inhibited in the stock bottle for periods ranging from one to six months. However, in the dispensing bottle in which the contents were repeatedly exposed to the atmosphere, deterioration was rapid and the supply had to be frequently replaced.

The reliability of such solutions is not satisfactory where mass production techniques are required. In addition we have one or more isolated insular stations where iodometric work is being performed by persons without chemical training and using limited facilities. Our goal then, has been to find a starch indicator simple to prepare, economical to use, and free from hydrolytic deterioration for at least a year and preferably longer.

Experience with different methods of preserving aqueous suspensions indicated that the most satisfactory way to obtain the stability we desired was to work with a nonaqueous medium, which in itself is an unfavorable ecological medium, rather than to rely on toxic additives to suppress biotic activity in a highly favorable growth medium. A modified starch glycerite was considered. Referring to Walton (1928) again, we find that he catalogued eight abstracts covering the reactions of heated glycerine and starch. In these and subsequent publications there is a great diversity of opinion (frequently conflicting) as to the reaction(s) involved and the nature of the product(s) of such reactions. The following résumé concerning the formation of soluble starch illustrates the ambiguities in the literature:

A) Walton (1928 p. 11)

$$\text{Starch} \xrightarrow[\text{glycerin}]{\text{heat}} \frac{\text{soluble starch}}{\text{(blue iodine reac.)}} \longrightarrow \frac{\text{hexa saccharide}}{\text{(red iod. reac.)}} \longrightarrow \frac{\text{Trisaccharide}}{\text{(no iod. reac.)}}$$

B) Grant (1944 p. 802)

$$\text{Starch} \xrightarrow[\text{glycerin}]{\text{heat}} \frac{\text{Sol starch (amylodextrin)}}{\text{(yellow iod. reac.)}}$$

C) Ibid.

$$\text{Starch} \xrightarrow[\text{glycerin}]{\text{heat}} \text{Starch glycerite}$$

D) Bernthsen (1941 p. 372)

1. $\text{Starch} \xrightarrow[\text{acid}]{\text{cold, dil}} \text{soluble starch}$
2. $\text{Starch} \xrightarrow[\text{glycerin}]{\text{heat}} \text{soluble starch}$
3. $\text{Starch} \xrightarrow{\text{hydrolysis}} \frac{\text{amylodextrin}}{\text{(blue iod. reac.)}} \longrightarrow \frac{\text{erythrodextrin}}{\text{(red iod. reac.)}} \longrightarrow \frac{\text{achroodextrin}}{\text{(no iod. reac.)}}$

E) Gregory (1942 p. 602)

$$\text{Starch} \xrightarrow[\text{glycerin}]{\text{heat}} \frac{\text{soluble starch}}{\text{(amylodextrin)}}$$

The reader will note the contradictory statement concerning the color reaction of amylodextrin and the ambiguity of the references to starch glycerite and soluble starch. Until we understand the above reactions and can compare the spectral profiles of the reaction products, the term *modified starch glycerite* will be used arbitrarily in reference to the soluble starch-glycerin indicator described herein.

The indicator is prepared as follows:

1. Add 3 g of powdered soluble starch to 100 ml of glycerin and heat to 190°C.
2. Remove from heat and cool to room temperature. Developing turbidity may be ignored as it does not interfere with the efficacy of the indicator.

If the solution should gel with age reheat to 190°C and dilute with small amount of glycerin. Use 1 to 2 drops per 100 ml sample.

This indicator has been in use at this and other laboratories for approximately eight months. The solutions have been exposed to conditions favorable to deterioration such as exposure to light, air, etc. To date, there has been no indication of any deterioration. The color developed with a drop of the indicator is an intense blue with a sharp end point.

JOHN W. VAN LANDINGHAM
U.S. Bureau of Commercial Fisheries
Honolulu, Hawaii

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Marquesas Area Fishery and Environmental Data, January—March 1959

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UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

The series embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating Agencies and in processed form for economy and to avoid delay in publication.

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CAPE FALCON

MARQUESAS AREA FISHERY AND ENVIRONMENTAL DATA
JANUARY - MARCH 1959

By

Howard O. Yoshida
Fishery Research Biologist
United States Fish and Wildlife Service

Special Scientific Report--Fisheries No. 348
Washington, D. C.
June 1960

ABSTRACT

This report presents meteorological, oceanographic and fishery data collected aboard the Honolulu Biological Laboratory research vessel, *Charles H. Gilbert*, and a chartered West Coast tuna clipper, *Cape Falcon*, on expeditions to the southeastern Pacific Ocean centered in the Marquesas Islands during January-March 1959.

CONTENTS

Page

Introduction 1

Field procedures 1

  Bathythermograph and meteorological observations 1

  Productivity observations 3

  Surface trolling 3

  Live bait fishing 3

  Baitfish surveys 3

  Birds, tuna schools, and aquatic mammals 4

  Field party personnel 4

Laboratory procedures 4

  Salinity determinations 4

  Personnel processing samples and data 4

Literature cited 4

ILLUSTRATIONS

FIGURE Page

Frontispiece: The _Cape Falcon_ at anchor in Taiohae, Nuku Hiva

1. Track of the _Cape Falcon_ 1

1a. Track of the _Cape Falcon_ in the Marquesas Islands 2

2. Standardized inshore and offshore survey tracks, Marquesas area 2

3. Track of the _Charles H. Gilbert_ 3

TABLES

Page

1. Observations at bathythermograph lowerings, Charles H. Gilbert cruise 43 5
2. Environmental observations, Cape Falcon 12
3. Weather observations, Charles H. Gilbert cruise 43 15
4. Temperature and salinity of surface water in baiting areas, Charles H. Gilbert cruise 43 19
5. Transparency, water color, and related observations, Charles H. Gilbert cruise 43 . . 19
6. Surface troll catch and related data, Charles H. Gilbert cruise 43 20
7. Surface troll catch, Cape Falcon 21
8. Summary of pole-and-line fishing, Charles H. Gilbert cruise 43 22
9. Summary of pole-and-line fishing, Cape Falcon 23
10. Pole-and-line caught skipjack, yellowfin, and bigeye length frequency distribution, Charles H. Gilbert cruise 43 26
11. Pole-and-line caught skipjack and yellowfin length frequency distribution, Cape Falcon . 28
12. Summary of bait fishing, Charles H. Gilbert cruise 43 29
13. Summary of bait fishing, Cape Falcon 31
14. Length frequency distribution of Marquesan sardines, Tahitian sardines, and Tahitian nehu, Charles H. Gilbert cruise 43 31
15. Record of daily sightings of bird flocks, scattered birds, and tuna schools, Charles H. Gilbert cruise 43 32
16. Record of daily sightings of bird flocks, scattered birds, and tuna schools, Cape Falcon 34
17. Record of aquatic mammals sighted, Charles H. Gilbert cruise 43 36
18. Record of aquatic mammals sighted, Cape Falcon 36
19. Common and scientific names of fish caught 37

MARQUESAS AREA FISHERY AND ENVIRONMENTAL DATA
JANUARY - MARCH 1959

By

Howard O. Yoshida
Fishery Research Biologist
Honolulu Biological Laboratory
U. S. Bureau of Commercial Fisheries
Honolulu, Hawaii

This is the fourth report in a series presenting data obtained on cruises to the portion of the southeastern Pacific Ocean that is centered in the Marquesas Islands. The first report (Austin 1957) includes results of cruises made in August and September 1956. The second (Wilson and Rinkel 1957) includes data obtained from cruises made during January - March 1957, and the third (Wilson, et al. 1958) contains results from cruises made during October 1957 - June 1958.

The two expeditions made during January - March 1959 were the final in a program undertaken by the Honolulu Biological Laboratory (HBL), Bureau of Commercial Fisheries, to study the tuna resources of the southeastern Pacific Ocean. One of the expeditions was made on a chartered West Coast tuna clipper, the *Cape Falcon*, out of San Diego, to test the feasibility of fishing commercially for surface tuna schools in the Marquesas area. The other expedition was made on the Bureau's research vessel *Charles H. Gilbert* to continue the investigation of surface tuna schools. As in the earlier reports, the data are presented without analysis so that they may be made available to other agencies studying the Pacific. Descriptive and analytical reports will follow.

The *Cape Falcon* departed San Diego January 26, 1959, for Almejas Bay, Baja California, where baiting operations were conducted from January 30 to February 5. Actual scouting and fishing for surface tuna schools in the Marquesas area (5°-20° S., 130°-150° W.) occupied the period from February 15 to March 15. The track of the *Cape Falcon* is shown in figures 1 and 1a.

The Gilbert departed Honolulu January 7, 1959 and returned on March 26, 1959. During the course of the cruise the following were accomplished: bait surveys in the Marquesas and Society Islands, a surface tuna school survey in the Tuamotu Archipelago, a standard inshore surface tuna school survey, and the north and south legs of a standard offshore surface tuna school survey in the Marquesas (fig. 2). The track of the *Gilbert* is shown in figure 3.

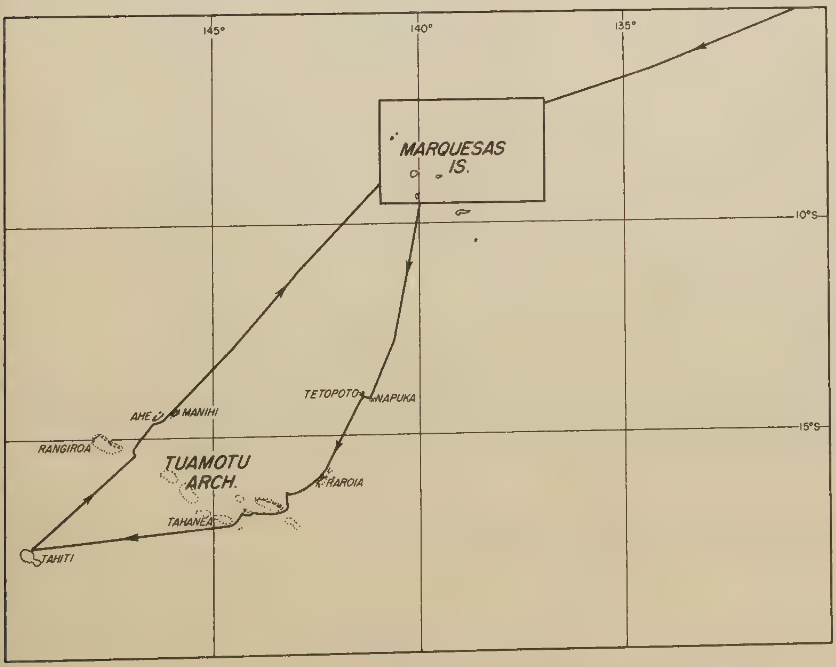

Figure 1.--Track of the *Cape Falcon*.

FIELD PROCEDURES

Bathythermograph and meteorological observations.

Bathythermograph (BT) lowerings during *Charles H. Gilbert* cruise 43 were made every 3 hours between Honolulu and 10° N. latitude, every 6 hours between 10° N. and 5° N. latitude, every 3 hours between 5° N. latitude and the Marquesas, at local noon daily during the inshore survey, every 3 hours during the southbound legs of the offshore survey, at each tuna fishing station, and at 0900 and 1400 daily between the Marquesas and Tahiti. BT lowerings totaled 224 during *Gilbert* cruise 43.

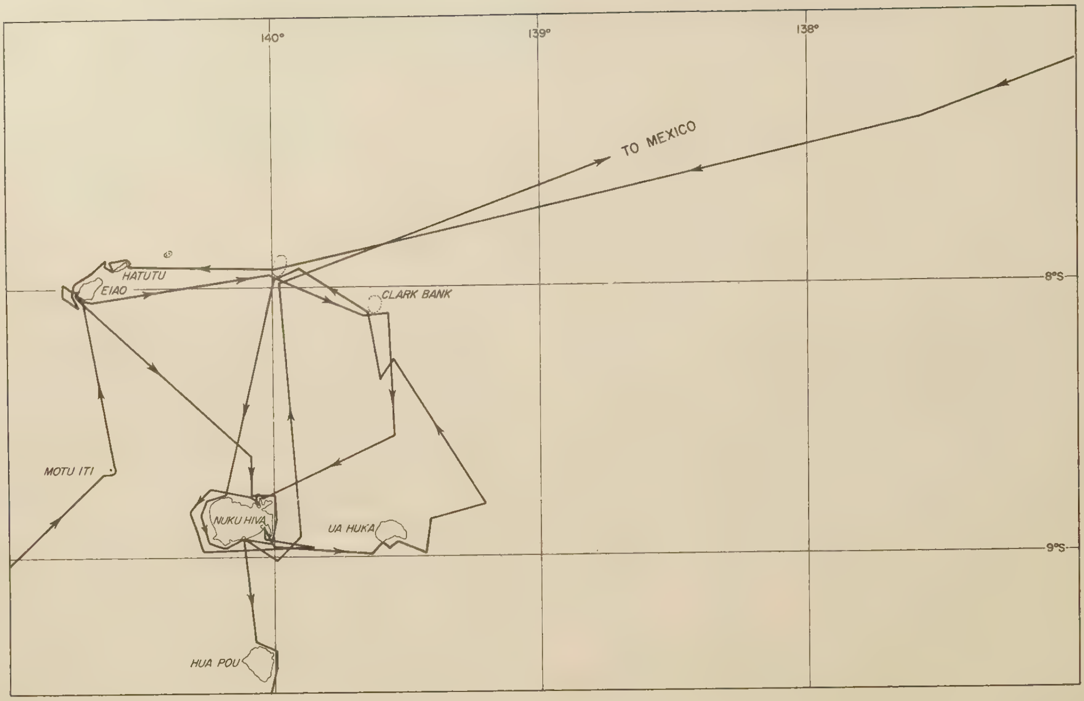
140°
139°
138°
TO MEXICO
HATUTU
EIAO
CLARK BANK
8°S
MOTU ITI
NUKU HIVA
UA HUKA
9°S
HUA POU

Figure 1a. --Track of the Cape Falcon in the Marquesas Islands.

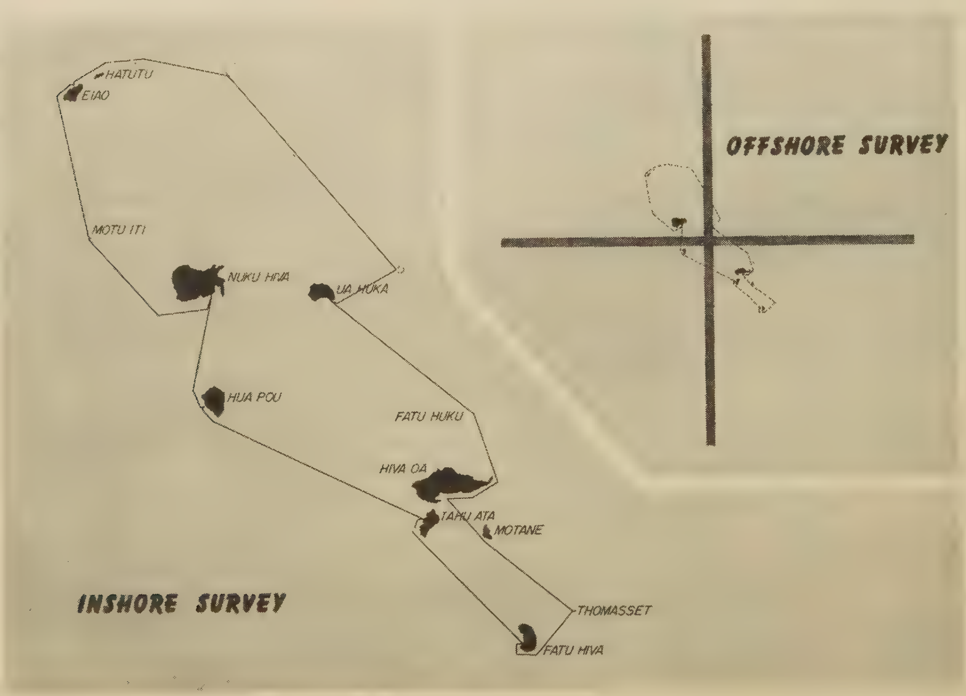
HATUTU
EIAO
OFFSHORE SURVEY
MOTU ITI
NUKU HIVA
UA HUKA
HUA POU
FATU HUKU
HIVA OA
TAHU ATA
MOTANE
INSHORE SURVEY
THOMASSET
FATU HIVA

Figure 2. --Standardized inshore and offshore survey tracks, Marquesas area.

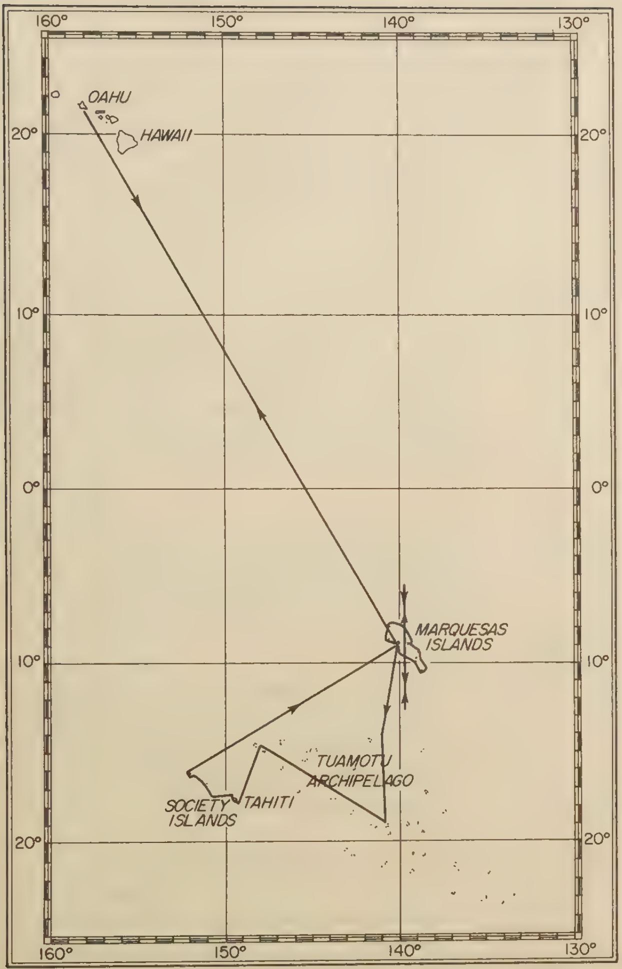

Figure 3. --Track of the Charles H. Gilbert.

Entries were made on Oceanographic Log Sheet "B" in conjunction with BT lowerings. These entries were coded according to Hydrographic Office Publication 606-c and are reproduced in table 1. Included in this table are salinity determinations of surface water samples taken at BT lowerings.

Standard weather observations were made up to 4 times daily during Gilbert 43. The observations were coded according to U. S. Weather Bureau Form 1210-F and are presented in table 3.

Although no bathythermograph lowerings or standard weather observations were made on board the Cape Falcon, the Government observer made routine observations on the environment which were coded and recorded on Oceanographic Log Sheet "B". These observations are presented in table 2, which also includes salinity determinations of surface water samples taken in conjunction with some of the environmental observations.

Productivity observations

Water transparency observations using a 30 cm. Secchi disc and water color observations by comparison with the Forel standard were made at local noon daily during Gilbert 43 while in the Marquesas area (table 5).

A study of the rate of carbon dioxide uptake by the C^{14} method was made in various localities between Hawaii, the Marquesas, and the Society Islands in collaboration with the Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.), Australia and the University of Hawaii. The results of this study will be published elsewhere.

Surface trolling

Varying numbers of lines were trolled from the Gilbert while running to and from the survey areas and while scouting for surface schools. The catches and related data are given in table 6.

Varying numbers of lines were trolled from the Cape Falcon, while scouting for surface schools in the survey areas. The troll catches are presented in table 7.

Live-bait fishing

The live-bait pole-and-line fishing techniques used on Gilbert 43 were similar to those of the Hawaiian skipjack fishery (June 1951). Marquesan sardines were used as bait. The results of fishing and other related data are presented in table 8. The length-frequency distribution of samples of skipjack, yellowfin, and bigeye caught are given in table 10.

The fishing techniques of California baitboat fishermen were used aboard the Cape Falcon. A description of the techniques is given by Godsil (1938). Anchovetas obtained at Almejas Bay, Baja California, were used as bait. The results of fishing and other pertinent data are presented in table 9. The length-frequency distribution of samples of yellowfin and skipjack caught are given in table 11.

Baitfish surveys

Descriptions of procedures used in conducting baitfish surveys in the Marquesas have appeared in earlier publications (Wilson and Rinkel 1957, and Wilson, et al. 1958). The results of bait surveys and bait fishing operations during Gilbert cruise 43 are presented in table 12. The length-frequency distributions of bait samples are presented in table 14, and observations of surface water temperature and salinity at baiting localities are presented in table 4.

As noted earlier, bait for pole-and-line fishing from the Cape Falcon was obtained in Almejas Bay, Baja California. The gear and methods of baiting employed on the Cape Falcon are similar to those used by California baitboat fishermen. A description of the gear and methods is given by Alverson and Shimada (1957) and will not be repeated here. The results of baiting in Almejas Bay appear in table 13, which also includes results of two days of baiting in the bays of the Marquesas.

Birds, tuna schools, and aquatic mammals

A watch was maintained during daylight hours for birds, tuna schools, and aquatic mammals aboard both the Cape Falcon and the Gilbert. Summaries of these observations are presented in tables 15 through 18, inclusive.

Field party personnel

Charles H. Gilbert

William T. Tanaka, Master
Robert C. Wilson, Field Party Chief
Richard J. Hansen, Fishery Aid
Harry R. Jitts, Collaborator,
C.S.I.R.O., Australia

Cape Falcon

Sverre Jangaard, Master
Thomas S. Hida, Observer

LABORATORY PROCEDURES

Salinity determinations

A modification of the Knudsen method (Van Landingham 1957) was used in analyzing the surface water samples.

Personnel processing samples and data
(In addition to the author)

Arthur Oishi, Fishery Aid
Betty Ann L. Keala, Statistical Clerk

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1958. Marquesas area fishery and environmental data, October 1957 - June 1958. U. S. Fish and Wildlife Service, Special Scientific Report -- Fisheries 283. 105 pp.

Table 1.--Observations at bathythermograph lowerings, Charles H. Gilbert cruise 43

Ser. No.	Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Baro-meter, mb.	Wea-ther	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
						Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
1	0000	1/10	18°17.0'N	155°27.5'W	76.5	11	06	76.8	73.2	1012	60	0	8	7	2	12	1	34.59
2	0300	1/10	17°55.0'N	155°15.0'W	77.5	11	07	78.0	75.0	1011	01	6	5	9	1	12	1	34.36
3	0600	1/10	17°31.5'N	155°00.0'W	77.0	07	09	77.1	74.5	1014	00	6, 8	2	8	1	12	1	34.47
4	0900	1/10	17°10.0'N	154°47.0'W	76.0	02	05	77.6	74.5	1015	00	6	2	8	1	12	1	34.41
5	1200	1/10	16°47.0'N	154°34.5'W	77.6	09	08	77.5	74.5	1012	00	X	9	8	1	12	1	34.25
6	1500	1/10	16°25.0'N	154°21.5'W	76.2	03	06	78.3	74.6	1014	00	6	3	8	1	12	1	34.29
7	1800	1/10	16°03.0'N	154°07.5'W	77.5	09	11	78.0	74.5	1013	03	6, 1	7	8	2	09	2	34.23
8	2100	1/10	15°41.0'N	153°54.0'W	78.1	10	10	79.4	74.9	1014	01	1, 6, 8	3	8	2	12	2	34.32
9	0000	1/11	15°18.0'N	153°43.5'W	78.6	02	05	78.6	74.4	1012	02	1, 6	2	9	2	12	2	34.38
10	0300	1/11	14°54.0'N	153°34.0'W	77.8	06	12	78.5	74.5	1012	02	1, 6	2	9	2	11	2	34.52
11	0600	1/11	14°32.0'N	153°22.5'W	77.8	08	13	78.1	74.8	1013	00	X	9	9	2	09	2	34.48
12	0900	1/11	14°12.0'N	153°08.0'W	77.7	09	13	78.0	74.6	1013	00	1	3	8	2	11	2	34.39
13	1200	1/11	13°50.5'N	152°52.5'W	77.6	07	14	78.6	74.1	1010	00	1, 8	2	8	2	11	2	34.33
14	1500	1/11	13°30.0'N	152°37.5'W	77.3	08	14	77.8	74.0	1011	25	8	3	7	2	11	2	34.18
15	1800	1/11	13°07.5'N	152°25.0'W	77.5	06	14	80.5	75.0	1012	01	8, 1	2	8	2	10	2	34.15
16	2100	1/11	12°45.0'N	152°15.0'W	78.0	06	16	80.5	75.3	1011	03	1, 8	3	8	3	08	2	34.18
17	0000	1/12	12°24.0'N	152°04.5'W	77.9	06	16	79.5	75.0	1008	00	1, 8	2	8	3	12	2	34.13
18	0300	1/12	12°02.0'N	151°54.0'W	78.1	07	17	80.0	75.5	1009	02	8	3	8	3	11	2	33.93
19	0600	1/12	11°40.5'N	151°44.0'W	78.5	07	17	78.7	75.5	1010	02	8	3	8	3	11	2	34.03
20	0900	1/12	11°19.5'N	151°32.5'W	77.9	06	22	78.9	75.1	1010	02	8	3	7	3	11	2	34.03
21	1200	1/12	10°58.0'N	151°21.0'W	78.1	07	17	78.9	75.6	1008	02	8	3	8	4	11	2	33.92
22	1500	1/12	10°36.5'N	151°10.0'W	77.7	06	21	78.8	75.6	1008	02	8	4	7	3	11	2	33.96
23	1800	1/12	10°15.5'N	150°58.5'W	78.1	08	17	80.5	77.0	1010	03	8, 6	6	7	4	09	2	33.92
24	0000	1/13	09°35.0'N	150°33.0'W	79.3	08	18	80.3	77.0	1005	03	8	8	7	4	09	2	33.97
25	0600	1/13	08°54.5'N	150°01.0'W	80.5	10	19	81.0	77.6	1008	00	X	9	7	4	09	2	34.06
26	1200	1/13	08°15.0'N	149°29.0'W	81.4	13	14	81.0	77.8	1007	00	X	X	7	4	09	2	-
27	1800	1/13	07°34.0'N	148°57.0'W	82.2	09	22	78.2	77.5	1009	21	8	8	5	4	10	2	-
28	0000	1/14	06°51.5'N	148°25.0'W	80.3	14	16	82.0	77.0	1006	25	8	8	6	4	10	2	-
29	0600	1/14	06°15.0'N	147°58.5'W	81.4	14	16	81.1	77.0	1008	01	1, 8	2	7	4	15	2	-
30	1200	1/14	05°36.0'N	147°30.0'W	80.8	14	16	80.5	75.8	1008	03	8	3	7	4	15	2	-
31	1800	1/14	04°57.5'N	147°02.0'W	79.6	13	17	83.8	76.8	1010	02	8	3	7	4	13	2	-
32	2100	1/14	04°38.0'N	146°48.0'W	79.8	12	16	81.3	76.9	1009	03	1, 8	6	7	4	13	2	-
33	0000	1/15	04°16.0'N	146°35.5'W	80.0	11	16	81.0	75.2	1008	03	1, 8	4	7	4	12	2	-
34	0300	1/15	03°53.0'N	146°25.0'W	80.4	12	15	81.0	75.2	1008	01	1	2	8	3	12	2	-
35	0600	1/15	03°38.0'N	146°16.0'W	79.5	10	13	80.9	75.1	1011	01	1, 8	2	8	3	12	2	-

Table 1.--Observations at bathythermograph lowerings, Charles H. Gilbert cruise 43 - continued

Ser. No.	Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Barometer, mb.	Weather	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
						Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
36	0900	1/15	03°18.0'N	146°02.5'W	79.6	10	10	79.9	75.3	1011	02	1	2	8	3	12	2	-
37	1200	1/15	02°58.5'N	145°49.0'W	79.5	11	10	81.2	75.0	1010	03	1,6	8	8	3	12	2	-
38	1500	1/15	02°40.0'N	145°36.0'W	79.5	13	08	78.5	74.5	1010	02	1	2	8	3	12	2	-
39	1800	1/15	02°20.5'N	145°22.5'W	78.9	12	08	81.8	76.0	1012	02	8	2	9	3	12	2	-
40	2100	1/15	02°01.5'N	145°09.5'W	79.5	15	12	80.9	74.9	1011	03	1,6,8	4	9	3	12	2	-
41	0000	1/16	01°40.0'N	144°58.5'W	80.1	18	04	80.0	73.8	1008	02	1,8	2	8	1	12	2	-
42	0300	1/16	01°18.0'N	144°50.0'W	81.0	14	03	80.5	73.5	1008	02	1,8	2	9	1	12	2	-
43	0600	1/16	00°57.0'N	144°40.0'W	79.7	18	03	79.7	73.1	1011	01	1	1	9	1	12	2	-
44	0900	1/16	00°36.0'N	144°30.5'W	79.0	18	02	79.2	74.0	1010	02	1	2	8	1	12	2	-
45	1200	1/16	00°15.0'N	144°21.0'W	78.6	19	03	79.1	73.3	1009	01	1	2	8	1	12	2	-
46	1800	1/16	00°20.5'S	144°12.0'W	77.2	19	08	78.4	74.0	1010	01	X	0	9	1	12	1	-
47	2100	1/16	00°36.0'S	144°08.0'W	79.2	20	08	79.0	74.0	1008	02	X	0	9	1	12	1	-
48	0000	1/17	01°00.0'S	143°56.0'W	78.9	19	08	80.5	74.0	1006	02	X	0	9	1	12	1	-
49	0300	1/17	01°24.5'S	143°43.0'W	80.4	20	05	81.3	73.5	1007	02	8	1	9	1	12	1	-
50	0600	1/17	01°47.0'S	143°30.0'W	81.0	11	05	80.5	73.1	1009	01	X	0	9	1	12	1	-
51	0900	1/17	02°12.5'S	143°16.5'W	79.5	08	02	79.5	73.3	1008	02	X	0	9	1	12	1	-
52	1200	1/17	02°38.0'S	143°03.0'W	79.4	07	06	78.8	73.0	1007	03	8	1	9	1	12	1	-
53	1500	1/17	03°06.5'S	142°47.0'W	79.9	07	05	79.4	73.5	1008	02	8	1	9	1	12	1	-
54	1800	1/17	03°28.0'S	142°35.0'W	80.2	07	05	82.0	74.7	1010	03	8	3	9	1	12	1	-
55	2100	1/17	03°52.0'S	142°21.0'W	80.8	06	07	80.8	74.9	1009	02	8	3	9	1	12	1	-
56	0000	1/18	04°17.0'S	142°08.0'W	81.1	06	09	80.6	75.0	1008	02	8	3	9	1	12	1	-
57	0300	1/18	04°42.0'S	141°53.0'W	79.8	05	15	80.8	74.5	1008	02	8	3	9	2	12	1	-
58	0600	1/18	05°06.0'S	141°42.0'W	80.0	04	15	81.9	75.8	1010	01	8	2	9	2	12	1	-
59	0900	1/18	05°34.0'S	141°35.0'W	80.0	04	13	80.2	74.5	1010	02	8	4	8	2	12	1	-
60	1200	1/18	06°01.5'S	141°28.5'W	80.3	05	15	81.0	75.0	1010	01	8	2	8	2	12	1	-
61	1500	1/18	06°30.0'S	141°22.0'W	78.7	06	14	80.2	74.5	1010	02	8,1	2	9	2	12	1	-
62	1800	1/18	06°55.0'S	141°12.0'W	80.3	06	13	82.7	75.5	1012	03	8,1	5	9	3	12	1	-
63	2100	1/18	07°19.0'S	141°01.5'W	81.8	07	12	82.1	75.1	1012	01	8,1	3	9	3	12	1	-
64	0000	1/19	07°44.0'S	140°51.0'W	81.1	08	12	81.2	75.0	1010	02	8,1	3	9	2	12	1	-
65	0300	1/19	08°09.5'S	140°39.5'W	81.2	01	14	80.3	74.7	1010	02	1,8	4	9	3	09	1	-
66	0600	1/19	08°38.0'S	140°26.0'W	81.8	07	16	82.1	74.9	1012	03	4	7	9	3	09	1	-
67	1900	1/26	10°28.5'S	140°38.0'W	82.5	02	22	83.0	77.2	1011	21	6,8	8	7	4	02	1	-
68	0000	1/27	11°10.0'S	140°51.5'W	81.9	01	20	82.5	77.0	1008	02	6,8	8	7	4	02	2	35.68
69	1900	1/27	13°45.5'S	141°39.0'W	82.0	08	13	82.0	76.2	1011	01	6,8	7	7	4	02	2	-
70	0000	1/28	14°30.0'S	141°23.0'W	82.5	07	09	82.4	77.9	1010	02	6,8	7	7	2	04	2	35.77

Table 1.--Observations at bathythermograph lowerings, Charles H. Gilbert cruise 43 - continued

Ser. No.	Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Barometer, mb.	Weather	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
						Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
71	1900	1/28	15°52.0'S	141°36.0'W	82.3	08	16	83.6	76.3	1013	03	5,8	6	8	2	02	2	-
72	0000	1/29	15°52.0'S	142°24.0'W	82.3	10	09	83.0	78.0	1010	02	4,8	6	8	2	28	2	35.81
73	1900	1/29	16°15.0'S	142°53.5'W	82.2	08	14	84.5	77.5	1013	02	4,8	6	8	2	30	2	-
74	2130	1/29	16°27.0'S	143°03.0'W	82.3	08	14	83.0	76.8	1012	01	1,8	5	8	2	11	2	-
75	0000	1/30	16°34.0'S	143°28.0'W	82.0	05	14	81.5	77.0	1010	15	1,4,8	6	8	2	05	2	35.93
76	1900	1/30	16°15.5'S	144°03.5'W	81.8	07	09	82.7	75.0	1012	02	4,8	6	9	2	03	1	-
77	0000	1/31	16°01.0'S	144°50.0'W	83.5	09	11	84.5	76.3	1010	02	4,8	6	9	2	10	1	35.93
78	1845	1/31	15°43.5'S	145°12.0'W	83.4	11	05	83.5	76.5	1012	02	1,8	2	9	2	02	1	-
79	2248	1/31	15°53.0'S	145°36.0'W	85.4	07	03	83.5	75.6	1010	02	8,9	2	9	1	01	2	-
80	2253	1/31	15°53.0'S	145°36.0'W	85.4	07	03	83.5	75.6	1010	02	8,9	2	9	1	01	2	-
81	2258	1/31	15°53.0'S	145°36.0'W	86.5	07	03	83.5	75.6	1010	02	8,9	2	9	1	01	2	-
82	2303	1/31	15°53.0'S	145°36.0'W	86.2	07	03	83.5	75.6	1010	02	8,9	2	9	1	01	2	-
83	2308	1/31	15°53.0'S	145°36.0'W	86.5	07	03	83.5	75.6	1010	02	8,9	2	9	1	01	2	-
84	2313	1/31	15°53.0'S	145°36.0'W	86.2	07	03	83.5	75.6	1010	02	8,9	2	9	1	01	2	-
85	2318	1/31	15°53.0'S	145°36.0'W	86.4	07	03	83.5	75.6	1010	02	8,9	2	9	1	01	2	-
86	2323	1/31	15°53.0'S	145°36.0'W	84.9	07	03	83.5	75.6	1010	02	8,9	2	9	1	01	2	-
87	2328	1/31	15°54.5'S	145°39.0'W	85.3	07	03	83.5	75.6	1010	02	8,9	2	9	1	01	2	35.90
88	1900	2/1	15°44.5'S	145°54.0'W	83.5	15	02	83.2	75.3	1011	02	8,5	3	9	0	03	2	-
89	2135	2/1	15°29.0'S	146°05.0'W	87.2	29	06	83.4	74.8	1010	02	8,5	2	9	0	03	2	-
90	0000	2/2	15°34.0'S	146°25.0'W	85.6	29	06	83.3	72.6	1008	02	8	2	9	0	04	1	35.89
91	1720	2/2	15°30.0'S	146°36.0'W	83.5	XX	00	83.0	76.2	1009	15	8,1	3	9	0	32	2	-
92	1900	2/2	15°24.5'S	146°50.5'W	84.0	XX	00	84.2	76.5	1009	03	8	3	9	0	32	2	-
93	0000	2/3	15°05.0'S	147°21.5'W	84.1	04	08	83.0	75.0	1008	16	6,8	3	9	1	34	2	35.82
94	1900	2/3	15°03.0'S	147°59.5'W	83.1	11	09	83.1	76.5	1009	16	9,6	4	9	1	32	2	-
95	0000	2/16	16°01.5'S	150°55.0'W	83.4	25	13	83.7	78.3	1010	14	8,0	6	8	1	35	2	35.50
96	0300	2/16	15°45.0'S	150°33.0'W	83.3	30	11	84.0	79.0	1010	02	8,0	6	8	1	32	2	-
97	0600	2/16	15°28.5'S	150°11.5'W	83.2	32	08	83.0	77.7	1012	01	8	3	8	1	32	2	-
98	0900	2/16	15°12.0'S	149°49.5'W	82.8	33	07	82.9	77.5	1012	01	8	2	7	1	32	2	-
99	1200	2/16	14°55.5'S	149°27.0'W	83.4	32	08	82.4	76.1	1011	01	8	1	8	1	32	2	-
100	1500	2/16	14°39.0'S	149°05.0'W	83.1	30	06	83.2	77.7	1011	02	8	1	8	1	32	2	-
101	1800	2/16	14°24.0'S	148°42.0'W	82.9	31	09	83.0	76.7	1013	01	1,8	2	8	1	32	2	-
102	2100	2/16	14°09.0'S	148°20.0'W	84.0	31	10	83.4	77.0	1012	03	1,6,8	6	8	1	09	2	-
103	0000	2/17	13°54.0'S	147°58.0'W	84.0	32	10	84.0	78.0	1010	03	1,8	6	8	1	09	2	35.57
104	0300	2/17	13°38.0'S	147°39.0'W	84.2	31	10	85.5	79.0	1010	XX	8,0	4	8	2	30	2	-
105	0600	2/17	13°24.0'S	147°13.0'W	83.5	33	13	83.0	78.4	1012	01	8	3	8	2	30	2	-

Table 1.--Observations at bathythermograph lowerings, Charles H. Gilbert cruise 43 - continued

Ser. No.	Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Barometer, mb.	Weather	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
						Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
106	0900	2/17	13°09.0'S	146°48.0'W	83.3	32	15	82.8	78.2	1012	02	8	2	8	2	30	2	-
107	1200	2/17	12°53.5'S	146°24.0'W	83.0	32	17	82.1	78.8	1010	03	8	5	8	2	30	2	-
108	1500	2/17	12°38.0'S	145°59.0'W	83.2	33	21	83.5	77.7	1010	02	6	4	8	3	30	2	-
109	1800	2/17	12°24.0'S	145°38.0'W	81.9	32	22	82.8	78.4	1012	03	8, 0	6	8	3	30	2	-
110	2100	2/17	12°10.5'S	145°17.5'W	82.2	33	21	86.0	78.9	1012	02	8, 6	6	8	3	36	2	-
111	0000	2/18	11°56.5'S	144°57.0'W	82.2	33	25	83.0	77.5	1010	03	8, 6	8	8	3	36	3	-
112	0300	2/18	11°42.5'S	144°36.0'W	81.5	34	19	80.2	77.0	1010	02	8, 6	8	8	4	36	3	35.42
113	0600	2/18	11°28.5'S	144°15.5'W	80.0	32	18	82.1	77.9	1012	50	6, 8	8	7	3	36	3	-
114	0900	2/18	11°15.0'S	143°55.0'W	81.5	34	19	82.7	77.5	1012	50	X	8	6	3	36	3	-
115	1200	2/18	11°00.5'S	143°34.0'W	81.8	34	21	82.0	77.0	1010	02	8	8	6	3	36	3	-
116	1500	2/18	10°46.5'S	143°13.5'W	82.4	34	20	82.0	76.8	1011	15	8, 6	8	6	5	36	3	-
117	1800	2/18	10°32.0'S	142°52.5'W	81.0	34	23	82.5	76.2	1013	15	8, 6	8	7	4	36	3	-
118	2100	2/18	10°18.0'S	142°31.5'W	82.1	34	19	82.8	77.1	1012	15	8, 6	8	7	4	36	3	-
119	0000	2/19	10°03.0'S	142°10.0'W	82.1	36	15	83.2	76.8	1011	01	8, 6	6	8	3	36	3	35.80
120	0300	2/19	09°49.0'S	141°50.0'W	82.3	35	14	83.0	77.2	1011	02	5, 6	8	6	3	00	1	-
121	0600	2/19	09°35.5'S	141°30.0'W	82.2	01	13	82.5	77.1	1013	03	5, 6	8	7	3	00	1	-
122	0900	2/19	09°21.5'S	141°09.0'W	81.5	04	17	82.2	76.8	1012	01	8, 5	5	7	2	00	1	-
123	1200	2/19	09°07.5'S	140°48.0'W	82.1	03	13	79.6	77.0	1012	02	8, 5	5	7	2	00	1	-
124	2200	2/22	08°38.0'S	140°25.0'W	82.5	04	10	81.8	76.5	1010	00	6, 8	6	7	1	05	1	-
125	2242	2/22	08°35.0'S	140°28.0'W	82.0	06	09	83.1	76.2	1010	02	6, 8	6	7	1	05	1	-
126	2200	2/23	07°53.0'S	139°59.0'W	82.7	07	11	81.0	73.8	1011	01	1, 6, 8	2	8	1	08	1	-
127	0000	2/24	08°01.5'S	139°45.0'W	82.5	06	11	83.7	75.0	1009	03	1, 8	4	8	1	08	1	-
128	0120	2/24	08°05.0'S	139°39.5'W	83.0	06	11	83.5	74.8	1009	02	1, 8	4	8	1	08	1	-
129	2010	2/24	08°34.0'S	139°14.0'W	82.2	07	14	83.0	73.7	1012	02	8	2	9	2	12	1	-
130	2200	2/24	08°43.0'S	139°13.0'W	82.5	08	13	82.5	73.0	1011	01	6, 8	2	9	1	12	1	-
131	2200	2/25	09°35.0'S	138°50.0'W	82.1	09	12	82.5	76.5	1011	03	6, 8	6	8	1	09	1	-
132	2010	2/26	10°13.0'S	138°33.0'W	83.2	06	12	83.7	75.0	1012	00	8	1	9	1	05	1	-
133	2200	2/26	10°21.5'S	138°26.0'W	83.0	08	13	83.3	73.2	1011	02	8	1	9	1	06	1	-
134	2200	2/27	09°49.0'S	139°09.0'W	83.5	34	03	85.3	75.0	XX	01	8	3	9	1	01	1	-
135	2345	2/27	09°50.0'S	139°17.5'W	83.0	04	13	83.5	74.5	1010	02	8	2	9	1	01	1	-
136	2245	2/28	09°31.0'S	140°05.5'W	83.2	08	15	83.2	74.0	1010	02	8	1	9	1	02	1	-
137	1900	3/3	08°50.0'S	139°40.0'W	82.5	11	14	82.8	76.0	1013	02	8	2	9	2	07	1	-
138	0600	3/5	05°23.5'S	139°42.5'W	79.8	12	17	80.5	74.9	1010	00	8	1	9	2	08	1	35.25
139	0900	3/5	05°43.5'S	139°46.0'W	79.5	11	14	80.5	74.0	1010	00	X	1	8	2	07	1	35.32
140	1200	3/5	06°04.0'S	139°49.0'W	80.0	10	18	80.0	74.7	1009	00	8	1	8	2	07	1	35.33

Table 1.--Observations at bathythermograph lowerings, *Charles H. Gilbert* cruise 43 - continued

Ser. No.	Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Barometer, mb.	Weather	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
						Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
141	1500	3/5	06°24.5'S	139°52.0'W	79.8	10	13	80.3	75.0	1010	02	8	1	9	2	07	1	35.39
142	1800	3/5	06°47.5'S	139°49.0'W	80.2	10	11	80.1	76.0	1012	03	8, 0	5	9	2	07	1	-
143	2030	3/5	07°06.5'S	139°48.0'W	81.5	13	07	82.0	75.6	1011	02	6	6	9	2	07	1	35.35
144	2330	3/5	07°21.5'S	139°47.0'W	82.3	06	07	82.3	77.1	1009	-	8	2	9	2	07	1	-
145	0300	3/6	07°48.5'S	139°44.0'W	82.0	10	12	82.4	76.3	1008	02	8, 1	3	9	2	10	1	35.63
146	0600	3/6	08°11.0'S	139°46.0'W	81.7	10	16	82.1	75.0	1010	00	8	2	8	2	10	1	35.81
147	0900	3/6	08°30.0'S	139°56.0'W	81.8	12	14	82.0	75.4	1010	00	X	1	8	1	10	1	35.88
148	1800	3/8	09°25.0'S	139°36.0'W	82.0	07	15	82.8	76.3	1011	00	8	2	9	2	09	1	-
149	2030	3/8	09°40.0'S	139°35.5'W	83.3	07	16	83.0	75.8	1013	03	8, 6	4	8	3	09	1	35.95
150	2255	3/8	09°58.5'S	139°39.0'W	83.6	06	14	83.3	75.3	1009	01	8	3	8	3	09	1	-
151	0000	3/9	10°05.0'S	139°39.0'W	82.5	10	15	83.2	75.0	1008	01	8	1	8	3	09	1	35.99
152	0300	3/9	10°26.5'S	139°40.0'W	82.4	08	11	82.9	75.3	1009	00	8	1	9	2	14	1	35.99
153	0600	3/9	10°49.0'S	139°41.0'W	82.8	10	15	82.9	75.2	1011	00	8	2	8	1	14	1	36.03
154	0900	3/9	11°10.0'S	139°41.0'W	82.1	10	13	82.4	76.0	1011	00	X	2	8	1	14	1	36.04
155	1200	3/9	11°30.0'S	139°41.5'W	82.6	11	14	81.0	76.2	1010	00	8	4	8	1	14	1	36.04
156	1500	3/9	11°51.0'S	139°42.0'W	82.4	09	16	81.5	77.4	1010	00	8	2	8	2	12	1	36.04
157	1800	3/9	12°09.0'S	139°44.0'W	83.0	08	15	82.8	76.3	1012	50	8, 6	6	8	2	14	1	36.04
158	2100	3/9	12°27.0'S	139°45.0'W	83.4	09	14	83.1	76.8	1011	15	1, 6, 8, 9	4	8	2	14	1	36.07
159	0000	3/10	12°44.0'S	139°48.0'W	82.9	09	10	83.8	77.0	1009	02	8	3	8	2	09	1	36.03
160	0300	3/10	13°01.5'S	139°50.5'W	83.5	11	13	83.4	77.0	1010	14	8, 1	5	8	1	12	1	36.03
161	0045	3/11	10°37.0'S	139°38.5'W	83.7	10	11	83.1	75.9	1009	01	8	4	8	1	11	1	-
162	0000	3/17	08°34.5'S	140°27.0'W	83.6	08	12	83.5	77.5	1011	01	6, 8	3	8	2	06	1	35.91
163	0300	3/17	08°09.0'S	140°43.5'W	82.8	08	14	83.7	77.3	1012	02	8	2	8	3	14	1	-
164	0600	3/17	07°45.0'S	140°59.0'W	82.3	10	12	82.8	76.6	1013	02	8	2	8	2	06	1	-
165	0900	3/17	07°20.5'S	141°14.5'W	82.2	10	16	82.2	76.5	1013	02	8	2	8	2	09	1	-
166	1200	3/17	06°55.4'S	141°30.0'W	82.0	07	14	81.4	76.5	1012	01	8	1	8	2	09	1	-
167	1500	3/17	06°31.0'S	141°45.5'W	81.1	07	14	79.3	74.7	1013	20	8	6	8	3	09	1	-
168	1800	3/17	06°07.0'S	142°00.0'W	81.3	09	17	81.9	76.2	1015	01	8	2	8	2	05	1	-
169	2100	3/17	05°42.0'S	142°14.0'W	82.2	07	13	82.0	75.5	1014	02	8	2	8	2	09	1	-
170	0000	3/18	05°18.0'S	142°29.0'W	82.0	06	11	81.6	75.2	1012	03	4, 8	5	8	2	03	1	35.34
171	0300	3/18	04°54.0'S	142°45.0'W	82.1	07	12	83.4	75.5	1012	01	8	2	8	2	04	1	-
172	0600	3/18	04°20.0'S	143°01.0'W	81.1	09	13	81.1	75.0	1014	02	8	2	8	2	05	1	-
173	0900	3/18	04°06.0'S	143°16.5'W	80.8	06	07	81.8	74.8	1014	02	8	2	8	2	05	1	-
174	1200	3/18	03°42.0'S	143°32.5'W	81.0	08	07	79.5	73.9	1012	03	8	3	8	1	05	1	-
175	1500	3/18	03°17.0'S	143°49.0'W	80.8	10	11	79.7	74.6	1013	01	8	2	8	1	05	1	-

Table 1.--Observations at bathythermograph lowerings, Charles H. Gilbert cruise 43 - continued

Ser. No.	Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Baro-meter, mb.	Wea-ther	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
						Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
176	1800	3/18	02°52.5'S	144°05.0'W	80.6	11	11	80.4	74.8	1014	02	8	2	8	1	04	1	-
177	2100	3/18	02°28.0'S	144°20.0'W	82.1	12	10	82.5	76.1	1012	02	8,6	2	8	1	09	2	-
178	0600	3/19	02°06.0'S	144°36.0'W	81.1	12	11	81.0	76.0	1013	02	8	2	8	1	05	1	-
179	0900	3/19	01°41.0'S	144°49.0'W	81.0	11	10	81.0	76.3	1013	02	8	2	8	1	07	1	-
180	1200	3/19	01°16.0'S	145°03.0'W	80.6	11	09	80.5	75.9	1012	01	8	2	8	1	07	1	-
181	1500	3/19	00°51.0'S	145°16.0'W	80.3	13	11	79.3	75.6	1013	02	8	2	8	2	05	1	-
182	1800	3/19	00°24.5'S	145°30.0'W	80.5	18	11	83.2	76.8	1015	02	8	2	9	1	10	1	-
183	2100	3/19	00°02.0'S	145°44.0'W	81.3	15	12	82.0	76.5	1013	02	8	2	8	2	07	1	-
184	0000	3/20	00°13.5'N	145°54.5'W	81.3	17	12	85.0	78.1	1010	03	4,8	3	8	2	16	1	35.00
185	0300	3/20	00°40.0'N	146°11.0'W	81.1	13	10	82.2	76.3	1011	03	4,8	5	8	2	12	1	-
186	0600	3/20	01°07.5'N	146°26.0'W	80.7	11	08	81.5	76.7	1013	03	8,4,2	6	7	1	12	1	-
187	0900	3/20	01°35.0'N	146°39.0'W	80.7	11	13	80.7	76.0	1013	03	8,4,2	8	8	2	12	1	-
188	1200	3/20	02°02.0'N	146°52.0'W	81.0	11	12	80.2	76.4	1010	00	8,4,2	7	8	2	12	1	-
189	1500	3/20	02°31.0'N	147°06.0'W	81.0	10	10	80.5	76.4	1011	01	8	6	7	2	12	1	-
190	1800	3/20	02°59.0'N	147°19.5'W	81.1	10	09	82.1	77.0	1013	01	8,4,1	3	9	1	12	1	-
191	2100	3/20	03°28.0'N	147°33.0'W	81.1	10	13	81.7	77.3	1012	03	6,4	6	9	2	04	1	-
192	0000	3/21	03°53.0'N	147°44.5'W	82.5	08	09	81.8	76.4	1010	01	4,6,8	4	8	2	04	1	34.86
193	0300	3/21	04°18.0'N	147°55.0'W	82.7	08	13	82.2	77.0	1010	03	1,8,6	5	8	2	04	1	-
194	0600	3/21	04°43.5'N	148°05.0'W	82.2	08	12	82.0	77.1	1012	02	8,4	3	8	2	04	1	-
195	1200	3/21	05°38.5'N	148°25.0'W	82.0	07	18	80.1	77.0	1010	16	8,4	4	8	2	04	1	-
196	1800	3/21	06°32.5'N	148°44.0'W	81.5	05	15	80.9	77.3	1013	21	6	8	6	3	04	1	-
197	0000	3/22	07°07.0'N	149°00.5'W	82.0	07	20	81.3	76.9	1010	20	8,4	8	6	3	04	1	34.33
198	0600	3/22	07°59.0'N	149°22.0'W	80.9	07	20	81.8	76.6	1012	01	4	6	5	3	04	1	-
199	1200	3/22	08°51.0'N	149°43.0'W	81.0	06	19	80.7	75.7	1010	00	8,4	6	6	3	04	1	-
200	1800	3/22	09°42.5'N	150°05.5'W	79.2	06	20	80.0	76.3	1013	18	6	7	7	4	04	1	-
201	0000	3/23	10°33.5'N	150°30.0'W	80.0	07	21	80.0	74.7	1011	00	4,6,8	7	8	3	04	2	-
202	0300	3/23	10°59.0'N	150°43.0'W	79.5	07	22	79.8	74.0	1011	02	6,8	7	7	3	06	2	-
203	0600	3/23	11°24.0'N	150°56.0'W	78.5	06	23	78.2	74.5	1013	00	6,8	7	6	3	06	3	34.25
204	0900	3/23	11°50.0'N	151°10.0'W	78.0	07	21	78.2	73.8	1014	02	6,8	8	7	4	06	3	34.06
205	1200	3/23	12°16.0'N	151°23.0'W	77.6	07	20	77.3	73.1	1013	00	6,8	6	6	3	06	3	34.13
206	1500	3/23	12°41.0'N	151°37.0'W	77.6	07	24	76.7	72.8	1013	14	8,6	7	6	4	06	2	34.17
207	1800	3/23	13°06.0'N	151°50.0'W	77.4	06	24	77.0	72.0	1015	14	8,6	7	6	4	07	4	34.18
208	2100	3/23	13°31.0'N	152°03.5'W	77.0	06	25	78.2	72.0	1016	01	8,6	3	6	4	06	3	34.24
209	0000	3/24	13°56.0'N	152°16.5'W	77.4	07	20	78.0	72.0	1014	03	8	4	7	4	06	3	34.25
210	0300	3/24	14°20.0'N	152°29.5'W	76.9	07	23	78.2	71.9	1014	02	8,6,4	6	6	4	06	2	34.30

Table 1.--Observations at bathythermograph lowerings, *Charles H. Gilbert* cruise 43 - continued

Ser. No.	Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Barometer, mb.	Weather	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
						Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
211	0600	3/24	14°44.0'N	152°42.0'W	75.5	07	24	76.5	71.6	1017	02	8, 6	7	6	4	06	3	34.33
212	0900	3/24	15°09.0'N	152°55.0'W	76.0	06	20	76.3	70.8	1019	01	8, 6	3	7	4	07	3	34.38
213	1200	3/24	15°34.0'N	153°05.5'W	76.0	07	15	75.3	69.5	1018	03	8, 6	7	7	4	06	3	34.37
214	1500	3/24	15°59.0'N	153°15.0'W	76.4	07	23	75.4	71.0	1017	01	4, 8	5	6	4	06	1	34.31
215	1800	3/24	16°24.5'N	153°25.0'W	75.6	07	22	75.8	70.5	1019	01	8, 6	2	8	3	06	1	34.30
216	2100	3/24	16°50.0'N	153°35.0'W	75.4	07	20	77.0	68.2	1020	03	8, 6	6	8	3	07	1	34.42
217	0600	3/25	17°05.5'N	154°00.0'W	76.2	08	20	76.3	70.1	1020	02	8, 6	7	6	3	06	2	34.35
218	0900	3/25	17°22.0'N	154°23.0'W	75.2	07	23	74.3	69.7	1024	25	6	8	5	3	07	2	34.41
219	1200	3/25	17°38.0'N	154°45.5'W	75.1	08	23	74.8	69.9	1020	01	6, 8	2	7	3	06	2	34.44
220	1500	3/25	17°54.0'N	155°07.0'W	75.0	08	20	74.7	70.0	1019	01	8	1	7	3	08	1	34.54
221	1800	3/25	18°11.0'N	155°27.5'W	73.9	06	24	74.8	70.5	1021	02	8	2	8	3	07	1	34.62
222	2100	3/25	18°29.0'N	155°45.0'W	74.2	06	22	73.5	70.8	1021	02	8	3	6	4	07	3	34.67
223	0000	3/26	18°48.0'N	156°00.0'W	76.1	08	20	75.1	71.0	1019	01	8	2	7	3	07	3	34.48
224	0300	3/26	19°09.0'N	156°13.0'W	77.5	06	08	76.9	70.8	1018	03	8	6	7	2	14	1	34.47

Table 2. --Environmental observations, Cape Falcon

Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Barometer, mb.	Weather	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
					Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
1600	2/6	22°08'N	114°12'W	73.4	02	10	69.1	61.5	1016	03	4,1	5	8	2	02	1	-
2300	2/6	21°06'N	115°10'W	74.4	36	10	71.6	64.4	1015	02	4,1	4	8	2	36	1	34.19
0400	2/7	20°37'N	115°39'W	73.6	02	08	69.8	61.5	1016	02	X	4	8	2	XX	X	-
1600	2/7	19°14'N	116°43'W	73.9	06	08	73.2	66.3	1017	03	4,1	6	8	1	31	1	-
2300	2/7	18°28'N	117°14'W	75.7	06	11	74.8	69.0	1014	02	4,8	7	8	2	34	1	33.96
0400	2/8	17°51'N	117°36'W	76.5	06	12	74.5	70.0	1015	02	X	5	8	2	XX	X	-
1600	2/8	16°22'N	118°28'W	77.9	09	16	77.3	72.0	1012	03	8,5	7	8	3	31	1	-
2300	2/8	15°29'N	119°05'W	78.7	09	12	79.7	74.0	1011	14	8,5	7	8	3	32	1	33.27
0400	2/9	14°46'N	119°24'W	78.7	09	12	79.2	74.3	1012	02	X	7	7	3	XX	X	-
1600	2/9	13°10'N	120°20'W	78.5	05	20	79.9	75.0	1012	01	8,4	3	8	3	05	1	-
2300	2/9	12°34'N	120°48'W	78.5	07	20	79.2	75.7	1010	15	8,4	6	7	3	07	1	33.38
0400	2/10	11°55'N	121°08'W	78.5	07	22	79.0	75.4	1011	02	8	6	7	3	XX	X	-
1600	2/10	10°25'N	121°55'W	79.5	07	22	79.8	76.0	1010	02	8,4	6	7	3	07	1	-
2300	2/10	09°41'N	122°41'W	79.8	07	22	81.0	77.0	1007	02	8	6	7	3	07	1	34.24
0400	2/11	09°03'N	122°56'W	80.0	07	22	79.0	76.4	1009	20	8	6	6	3	XX	X	-
1600	2/11	07°28'N	123°41'W	80.4	07	18	76.0	75.4	1009	51	8	9	6	3	07	1	-
2300	2/11	06°45'N	124°27'W	80.6	16	12	77.0	75.4	1007	50	8	8	7	3	07	1	34.41
0400	2/12	06°09'N	124°43'W	80.0	16	18	80.5	76.0	1009	15	8	7	7	3	XX	X	-
1600	2/12	04°34'N	125°26'W	80.0	14	20	80.8	76.1	1010	01	8,4	6	8	3	14	1	-
2300	2/12	03°47'N	125°18'W	80.0	14	20	80.2	75.7	1007	02	8,4	5	8	3	14	1	34.53
0400	2/13	03°13'N	125°38'W	79.9	14	22	79.7	75.3	1008	02	8	5	8	3	XX	X	-
1600	2/13	01°45'N	126°25'W	79.0	13	18	77.3	74.8	1010	50	8	7	7	3	13	1	-
2300	2/13	01°00'N	127°06'W	78.4	15	16	78.7	75.1	1007	01	8	1	8	3	15	1	34.77
0400	2/14	00°41'N	127°16'W	77.5	15	14	78.2	75.7	1008	02	8	1	7	3	XX	X	-
1600	2/14	01°10'S	128°10'W	77.8	15	18	79.0	75.3	1010	03	6	7	8	3	15	1	-
2300	2/14	01°56'S	129°02'W	79.0	13	16	81.0	76.0	1008	02	8	6	8	3	13	1	35.26
0500	2/15	02°50'S	129°20'W	78.8	13	18	79.5	75.0	1010	01	X	1	7	3	XX	X	-
1700	2/15	04°53'S	130°18'W	79.0	14	16	79.7	75.2	1012	03	8	6	8	3	14	1	-
0000	2/16	05°13'S	131°16'W	80.2	13	14	81.1	75.7	1010	02	8	7	8	3	13	1	35.42
0500	2/16	05°29'S	131°59'W	79.7	13	12	79.7	75.0	1012	01	8	2	8	2	13	1	-
1700	2/16	06°07'S	133°38'W	80.0	13	12	82.0	77.0	1014	02	8,1	2	8	2	13	1	-
0000	2/17	06°24'S	134°35'W	81.2	09	08	85.0	77.2	1012	02	8,1	2	8	2	09	1	35.34
0500	2/17	06°45'S	135°18'W	80.8	09	10	81.7	76.2	1013	01	X	1	8	2	09	1	-
1700	2/17	07°25'S	137°07'W	80.6	36	12	80.0	75.0	1014	02	8	1	8	2	09	1	-
0000	2/18	07°28'S	138°02'W	82.4	36	10	83.9	76.8	1012	02	8	1	8	2	09	1	35.74

Table 2. --Environmental observations, Cape Falcon - continued

Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Baro-meter, mb.	Wea-ther	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
					Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
0500	2/18	07°40'S	138°23'W	81.9	36	10	81.1	76.3	1014	03	8	5	8	2	09	1	-
0330	2/19	07°54'S	139°58'W	82.8	03	12	81.5	77.0	1012	02	8	6	8	3	03	1	35.97
1830	2/19	07°55'S	140°05'W	82.4	03	18	83.0	77.7	1014	02	8,1	4	8	3	03	1	-
1525	2/20	07°56'S	140°36'W	82.0	04	12	81.0	74.5	1012	14	8,1	6	8	2	04	1	35.86
1700	2/21	08°31'S	140°12'W	82.3	08	12	81.0	75.0	1012	01	8,4	2	8	2	08	1	-
0000	2/22	08°48'S	140°00'W	82.4	14	14	74.0	73.5	1009	61	0	9	5	3	09	1	35.72
0100	2/23	09°50'S	140°08'W	82.8	05	04	81.5	75.8	1009	01	8,1	6	8	1	05	1	35.94
0700	2/23	10°35'S	140°18'W	82.8	05	08	81.1	75.7	1012	02	8,1	6	8	1	05	1	-
1800	2/23	12°11'S	140°34'W	81.9	31	12	76.5	74.2	1012	21	8,5	7	6	2	06	1	-
0100	2/24	13°12'S	140°48'W	83.0	05	12	81.9	76.0	1010	01	8	5	8	2	06	1	35.66
1800	2/24	14°10'S	141°17'W	82.7	09	12	82.8	76.3	1014	02	1,8	5	8	2	09	1	-
0130	2/25	14°03'S	141°31'W	83.0	09	12	82.1	77.0	1010	01	8,1	2	8	2	09	1	35.67
0600	2/25	14°39'S	141°43'W	82.9	09	08	82.0	76.5	1013	02	8,1	2	8	2	09	1	-
1800	2/25	15°53'S	142°23'W	83.3	09	10	83.0	77.3	1015	02	8	3	8	2	09	1	-
0130	2/26	16°18'S	143°14'W	83.5	15	05	83.8	76.7	1012	01	8	2	8	1	00	0	35.83
0715	2/26	16°30'S	143°17'W	82.9	12	12	82.2	76.8	1013	02	X	2	8	2	XX	X	-
1800	2/26	16°46'S	143°25'W	82.7	10	09	85.4	76.8	1014	02	8	2	8	2	10	1	-
0230	2/27	16°58'S	144°35'W	83.2	09	10	83.0	76.0	1012	02	8	2	8	2	09	1	35.98
0600	2/27	17°03'S	145°07'W	82.9	09	12	82.5	76.6	1012	02	8	2	8	2	09	1	-
1800	2/27	17°12'S	146°55'W	83.3	12	10	82.9	77.3	1014	02	8	2	8	2	12	1	-
0100	2/28	17°17'S	147°52'W	83.0	09	12	86.4	77.9	1012	02	8	2	8	2	12	1	35.84
0600	2/28	17°22'S	148°34'W	83.0	09	10	83.2	77.0	1014	02	8	2	8	2	13	1	-
0030	3/2	16°54'S	148°51'W	84.0	09	12	83.6	77.8	1012	02	8,1	3	8	2	10	1	35.83
1800	3/2	15°22'S	146°55'W	83.6	09	12	84.4	77.6	1014	01	8	2	8	2	09	1	-
0100	3/3	14°53'S	146°28'W	84.5	08	14	84.0	77.8	1010	03	8	3	8	3	04	1	35.95
0600	3/3	14°14'S	145°55'W	83.7	08	16	83.9	77.7	1012	01	8	2	8	3	XX	X	-
1800	3/3	13°10'S	144°49'W	83.3	08	22	83.9	76.7	1014	02	8	2	8	3	06	1	-
0100	3/4	12°31'S	144°10'W	84.0	08	18	83.4	76.9	1010	02	8	2	8	3	06	1	35.52
0600	3/4	12°02'S	143°41'W	83.3	08	18	83.3	76.9	1012	02	8	2	8	3	XX	X	-
1800	3/4	10°45'S	142°39'W	83.0	09	18	83.9	77.9	1012	02	8	2	8	3	09	1	-
0100	3/5	10°10'S	142°05'W	83.4	09	20	83.3	77.4	1008	14	8	2	8	3	09	1	35.86
0600	3/5	09°42'S	141°37'W	83.1	09	18	83.1	77.6	1010	02	8	2	8	3	XX	X	-
1900	3/5	08°38'S	140°36'W	82.5	09	14	84.0	76.1	1012	02	8	2	8	3	09	1	-
0100	3/6	08°17'S	140°36'W	83.1	09	12	86.1	78.5	1009	03	8	3	8	3	09	1	35.86
1800	3/6	08°01'S	140°33'W	82.1	09	20	82.9	75.8	1012	01	8	1	8	3	09	1	-

Table 2. --Environmental observations, Cape Falcon - continued

Time, GCT	Date, 1959	Latitude	Longitude	Bkt. temp., °F.	Wind		Air temp.		Barometer, mb.	Weather	Clouds		Visibility	Sea	Swell		Surf. sal., ‰
					Dir., °T.	Force, kt.	Dry bulb, °F.	Wet bulb, °F.			Type	Cover			Dir. °T.	Amt.	
0100	3/7	07°57'S	139°57'W	82.8	09	14	82.1	75.3	1009	03	8	2	8	3	09	1	35.83
0530	3/7	07°54'S	139°58'W	82.5	09	10	81.8	75.9	1010	03	6,8	5	8	2	09	1	-
1830	3/7	07°57'S	139°52'W	82.4	09	14	83.1	76.9	1012	01	8	3	8	3	09	1	-
0630	3/8	08°22'S	139°40'W	82.3	09	14	82.9	76.3	1010	02	8	1	8	3	XX	X	-
1800	3/8	08°31'S	139°53'W	82.6	09	16	83.3	76.0	1011	03	8	4	8	3	09	1	-
1800	3/10	08°49'S	140°15'W	83.0	09	06	81.1	75.0	1012	20	8	5	8	1	09	1	-
0100	3/12	08°58'S	139°47'W	83.4	09	12	83.2	75.0	1009	14	8	2	8	3	09	1	36.03
1900	3/12	08°58'S	139°24'W	82.9	09	12	83.7	77.0	1013	03	8	4	8	3	09	1	-
0100	3/13	08°38'S	139°21'W	83.7	07	10	83.3	75.6	1010	01	8	2	8	2	07	1	35.96
0630	3/13	08°16'S	139°33'W	83.2	09	10	80.0	77.4	1012	51	8	3	6	2	09	1	-
1810	3/13	08°11'S	139°38'W	82.5	09	10	83.3	76.9	1013	14	8	3	8	2	09	1	-
0115	3/14	07°55'S	140°00'W	83.1	07	12	83.2	77.1	1010	02	8	3	8	2	07	1	35.74
0800	3/14	07°56'S	139°57'W	82.2	07	14	82.2	76.7	1013	02	8	3	8	3	07	1	-
1800	3/14	08°05'S	140°00'W	83.0	09	14	83.1	77.6	1014	02	8	3	8	3	09	1	-
0300	3/15	08°59'S	140°10'W	83.2	09	18	83.9	76.9	1011	01	8	2	8	3	09	1	36.0

Table 3.--Weather observations, Charles H. Gilbert cruise 43[1/]

Date, 1959	Latitude	Longitude	Time, GCT	Visibility	Wind		Weather		Pressure			Temperature			Clouds						Waves		
					Direction	Speed, kt.	Present	Past	Bar. corr., mb.	Characteristic	Amt. change	Dry bulb, °F.	Wet bulb, °F.	Sea water, °F.	Total amount	Amount low	Type low	Height low	Type middle	Type high	Direction	Period	Height
1/10	18.2°N	155.4°W	0000	98	11	06	60	5	1011.5	X	XX	76.8	73.2	76.5	8	8	7	5	X	X	12	2	2
1/10	17.5°N	155.0°W	0600	98	07	09	00	6	1013.5	2	2.0	77.1	74.5	77.0	2	2	4	5	0	0	12	2	2
1/10	16.7°N	154.5°W	1200	98	09	08	00	0	1011.5	7	1.5	77.5	74.5	77.6	X	X	X	X	X	X	12	2	2
1/10	16.0°N	154.0°W	1800	98	09	11	03	1	1012.9	2	2.0	78.0	74.5	77.5	7	5	4	5	0	5	09	6	3
1/11	15.2°N	153.6°W	0000	99	02	05	02	1	1011.5	7	3.0	78.6	74.4	78.6	2	2	4	5	0	5	09	6	3
1/11	14.3°N	153.2°W	0600	98	08	13	00	0	1012.9	2	2.0	78.1	74.8	77.8	X	X	X	X	X	X	09	3	3
1/11	13.8°N	152.9°W	1200	98	07	14	00	0	1010.5	7	3.0	78.6	74.1	77.6	2	1	1	4	0	1	11	3	3
1/11	13.0°N	152.2°W	1800	98	06	14	02	0	1012.2	2	3.0	80.5	75.0	77.5	2	1	3	5	0	1	09	2	3
1/12	12.3°N	152.0°W	0000	98	06	16	02	0	1008.5	7	3.0	79.5	75.0	77.9	2	1	4	5	0	1	12	2	4
1/12	11.5°N	151.5°W	0600	98	07	17	02	0	1010.2	2	2.0	78.7	75.5	78.5	2	1	4	5	0	1	11	2	4
1/12	10.9°N	151.1°W	1200	98	07	17	02	0	1008.5	7	2.0	78.9	75.6	78.1	2	2	4	5	0	0	11	2	4
1/12	10.3°N	150.7°W	1800	97	08	17	03	1	1009.8	2	2.0	80.5	77.0	78.1	6	6	1	5	0	0	09	2	4
1/13	09.5°N	150.6°W	0000	98	08	18	03	2	1005.1	7	3.0	80.3	77.0	79.3	8	8	1	4	X	X	09	2	4
1/13	08.9°N	150.2°W	0600	98	10	19	00	1	1008.1	2	3.0	81.0	77.6	80.5	X	X	X	X	X	X	09	2	4
1/13	07.9°N	149.7°W	1200	98	13	14	00	1	1006.8	7	1.0	81.0	77.8	81.4	X	X	X	X	X	X	09	2	4
1/13	07.5°N	149.5°W	1800	96	09	22	21	6	1009.1	2	3.0	78.2	77.5	82.2	8	8	7	3	X	X	10	2	4
1/14	06.5°N	149.0°W	0000	97	14	16	21	6	1005.8	7	2.0	82.0	77.0	80.3	8	8	7	3	X	X	10	2	4
1/14	06.0°N	147.8°W	0600	97	14	16	01	6	1007.8	2	2.0	81.1	77.0	81.4	3	2	1	3	0	1	15	2	4
1/14	05.5°N	147.4°W	1200	97	14	16	03	0	1007.5	7	1.0	80.5	75.8	80.8	3	3	1	3	0	0	15	2	4
1/14	04.8°N	147.1°W	1800	97	13	17	02	0	1009.8	2	2.0	83.8	76.8	79.6	3	3	1	4	0	0	13	2	4
1/15	04.2°N	146.5°W	0000	98	11	16	02	0	1007.8	7	3.0	81.0	75.2	80.0	4	3	1	4	0	8	12	2	4
1/15	03.6°N	146.1°W	0600	98	10	13	01	0	1010.8	2	3.0	80.9	75.1	79.5	2	1	1	3	0	8	12	2	3
1/15	02.8°N	145.8°W	1200	98	11	10	03	1	1009.5	7	2.0	81.2	75.0	79.5	8	8	4	3	X	X	12	2	3
1/15	02.2°N	145.5°W	1800	98	12	08	01	0	1012.2	2	2.0	81.8	76.0	78.9	2	2	2	4	0	0	12	2	3
1/16	01.6°N	144.9°W	0000	98	18	04	02	0	1008.1	6	2.5	80.0	73.8	80.1	2	2	2	4	0	1	12	2	2
1/16	00.2°N	143.3°W	0600	98	18	03	01	0	1010.8	2	2.0	79.7	73.1	79.7	1	1	2	4	0	0	12	2	2
1/16	00.1°N	144.1°W	1200	98	19	03	01	0	1008.8	7	1.5	79.1	73.3	78.6	1	1	2	4	0	0	12	2	2
1/16	00.7°S	144.1°W	1800	99	19	08	01	0	1010.2	1	1.0	78.4	74.0	77.2	0	0	0	9	0	0	12	2	1
1/17	01.9°S	144.0°W	0000	99	19	08	02	0	1006.1	7	2.0	80.5	74.0	78.9	0	0	0	9	0	0	12	2	1
1/17	02.0°S	143.6°W	0600	99	11	05	02	0	1009.1	2	2.0	80.5	73.1	81.0	0	0	0	9	0	0	12	2	1

[1/] All columns in USWB 1210-F are not included here. Those deleted are:

Column	2	Day of week	Column	23	Course of ship
"	3	Octant	"	24	Speed of ship
"	13	Barometer as read	"	31	Diff. sea-air, °F.
"	14	Barometer as corrected	"	32	Dew point, °F.
"	17	Air temperature, °F.			

Table 3. --Weather observations, Charles H. Gilbert cruise 43 - continued

Date, 1959	Latitude	Longitude	Time, GCT	Visibility	Wind		Weather		Pressure			Temperature			Clouds						Waves		
					Direction	Speed, kt.	Present	Past	Bar. corr., mb.	Characteristic	Amt. change	Dry bulb, °F.	Wet bulb, °F.	Sea water, °F.	Total amount	Amount low	Type low	Height low	Type middle	Type high	Direction	Period	Height
1/17	03.4°S	143.0°W	1200	99	07	06	03	0	1007.1	7	1.5	78.8	73.0	79.4	1	1	2	4	0	0	12	2	1
1/17	03.5°S	142.5°W	1800	99	07	05	03	0	1010.2	1	3.0	82.0	74.7	80.2	3	3	2	4	0	0	12	2	1
1/18	05.7°S	142.0°W	0000	98	06	09	02	0	1007.5	7	2.0	80.6	75.0	81.1	3	3	2	4	0	0	12	2	2
1/18	05.1°S	141.6°W	0600	98	04	15	01	0	1010.5	2	2.0	81.9	75.8	80.0	2	2	2	4	0	0	12	2	2
1/18	06.0°S	141.4°W	1200	98	05	15	01	0	1009.5	6	1.0	81.0	75.0	80.3	2	2	2	4	0	0	12	2	2
1/18	06.8°S	141.2°W	1800	98	06	13	03	1	1012.5	1	2.0	82.7	75.5	80.3	5	1	2	4	0	4	12	2	2
1/19	08.4°S	140.8°W	0000	98	08	12	02	0	1009.5	7	2.0	81.2	75.0	81.1	4	2	2	5	0	1	12	2	2
1/19	08.6°S	140.4°W	0600	98	07	16	03	1	1012.2	2	2.0	82.1	74.9	81.8	7	0	0	0	3	0	12	2	2
1/26	10.6°S	140.2°W	1800	98	02	22	20	6	1011.2	1	2.0	82.8	77.2	82.5	8	8	4	3	X	X	02	2	4
1/27	11.7°S	140.8°W	0000	97	01	20	02	5	1008.5	7	1.5	82.5	77.0	81.9	8	3	4	3	6	0	02	2	4
1/27	12.4°S	140.9°W	0600	96	02	21	21	6	1010.8	2	2.5	82.2	78.3	82.1	9	9	X	X	X	X	02	2	4
1/27	13.3°S	141.0°W	1200	96	02	21	00	6	1008.8	7	1.5	81.9	76.9	82.0	8	8	4	3	X	X	01	2	3
1/27	13.7°S	141.7°W	1800	97	07	15	02	6	1011.2	2	1.5	79.8	76.0	82.0	8	8	4	3	X	X	02	2	3
1/28	14.5°S	141.3°W	0000	97	07	09	01	2	1009.5	6	1.0	82.4	77.9	82.5	7	7	4	3	0	0	04	2	2
1/28	15.6°S	141.1°W	0600	97	08	12	02	2	1012.5	2	2.5	81.9	77.3	82.1	8	8	X	X	X	X	04	2	2
1/28	15.6°S	141.2°W	1200	97	07	14	01	2	1011.2	7	2.0	80.6	76.5	82.0	6	6	0	X	6	0	06	2	2
1/28	15.6°S	141.2°W	1800	98	07	18	03	1	1013.2	2	1.4	84.5	78.2	82.3	6	2	1	4	1	0	02	2	2
1/29	15.9°S	141.5°W	0000	98	10	09	02	2	1009.8	7	2.0	83.0	78.0	82.3	6	2	1	4	6	0	28	2	2
1/29	16.4°S	143.0°W	1800	99	08	14	02	2	1011.5	1	1.0	84.5	77.5	82.2	6	2	2	4	2	0	30	2	2
1/30	15.9°S	142.4°W	0000	99	05	14	15	1	1010.2	7	1.5	81.5	77.0	82.0	6	2	2	4	6	1	05	2	2
1/30	16.3°S	144.2°W	1800	99	07	09	02	2	1011.9	1	1.2	82.7	75.0	81.8	6	2	2	4	1	0	03	2	1
1/31	16.0°S	144.9°W	0000	99	09	11	02	2	1010.5	7	1.0	84.5	76.1	83.5	6	2	2	4	1	0	10	2	1
1/31	15.7°S	145.2°W	1800	99	07	04	01	1	1011.5	2	2.0	83.2	76.2	83.0	4	4	2	4	0	0	00	2	0
2/1	15.8°S	145.6°W	0000	99	07	03	03	0	1009.8	7	2.0	83.5	75.6	85.3	3	3	2	4	0	0	01	1	1
2/1	15.8°S	145.9°W	1800	99	00	00	01	0	1010.8	3	0.7	82.0	75.0	83.5	2	2	2	4	0	0	03	1	1
2/2	15.6°S	146.4°W	0000	99	29	06	02	0	1008.5	7	2.0	83.3	72.6	85.6	2	2	2	4	0	0	04	1	1
2/2	15.5°S	146.6°W	1800	99	00	00	02	0	1009.5	1	1.8	82.7	76.3	83.9	3	2	2	4	3	0	04	1	1
2/3	15.2°S	147.3°W	0000	99	04	08	16	0	1007.5	7	1.5	83.0	75.0	84.1	3	3	2	4	7	0	34	1	1
2/3	15.0°S	147.9°W	1800	98	03	13	03	2	1009.5	1	1.7	83.2	75.3	84.3	6	6	2	3	0	0	00	1	1
2/16	15.7°S	150.3°W	0000	99	25	13	14	2	1010.2	7	2.0	83.7	78.3	83.4	6	6	9	5	0	0	35	1	1
2/16	15.5°S	150.1°W	0600	98	32	08	01	1	1011.9	2	2.0	83.0	77.7	83.2	3	3	1	4	0	0	32	1	1
2/16	15.1°S	149.6°W	1200	98	32	08	01	0	1010.8	7	1.5	82.4	76.1	83.4	1	1	1	4	0	0	32	1	1
2/17	14.0°S	148.0°W	0000	98	32	10	03	1	1009.8	7	2.0	84.0	78.0	84.0	7	4	2	4	5	0	32	1	1
2/17	13.2°S	147.2°W	0600	98	33	13	01	1	1011.9	2	1.5	83.0	78.4	83.5	3	3	1	4	0	0	30	1	1
2/17	13.1°S	145.6°W	1200	98	32	17	03	1	1009.8	7	1.5	82.1	78.8	83.0	5	5	1	4	0	0	30	1	2
2/17	12.3°S	145.4°W	1800	98	32	22	03	1	1012.2	2	2.0	82.8	78.4	81.9	6	6	2	4	0	0	30	1	2
2/18	12.1°S	145.1°W	0000	98	32	25	03	2	1009.8	5	1.0	83.0	77.5	82.2	8	8	8	4	X	X	36	1	5
2/18	11.5°S	142.1°W	0600	97	32	18	50	2	1012.5	1	2.0	82.1	77.9	80.0	8	8	8	4	X	X	36	1	4
2/18	11.1°S	143.5°W	1200	97	34	21	02	5	1010.2	7	2.0	82.0	77.0	81.8	8	8	8	4	X	X	36	1	4
2/18	10.8°S	142.8°W	1800	98	34	23	15	8	1013.2	1	2.5	82.5	76.2	81.0	8	8	8	4	X	X	36	1	5

Table 3.--Weather observations, *Charles H. Gilbert* cruise 43 - continued

Date, 1959	Latitude	Longitude	Time, GCT	Visibility	Wind		Weather		Pressure			Temperature			Clouds						Waves		
					Direction	Speed, kt.	Present	Past	Bar. corr., mb.	Characteristic	Amt. change	Dry bulb, °F.	Wet bulb, °F.	Sea water, °F.	Total amount	Amount low	Type low	Height low	Type middle	Type high	Direction	Period	Height
2/19	10.3°S	142.0°W	0000	98	36	15	01	2	1010.8	7	1.5	83.2	76.8	82.1	7	7	8	4	0	0	36	1	3
2/19	09.7°S	141.2°W	0600	98	01	13	03	2	1012.9	2	2.5	82.5	77.1	82.2	8	8	8	4	X	X	00	1	3
2/19	09.2°S	140.8°W	1200	98	03	13	02	2	1011.5	6	2.0	79.6	77.0	82.1	5	3	1	4	1	0	00	1	2
2/23	08.6°S	140.6°W	0000	98	07	14	01	1	1009.1	6	2.0	81.9	75.4	82.3	5	5	8	4	0	0	03	1	2
2/23	08.0°S	139.8°W	1800	99	06	13	02	0	1012.9	2	2.0	82.0	74.6	81.6	2	1	2	6	5	0	03	1	2
2/24	08.4°S	139.4°W	1800	99	08	14	02	0	1013.2	2	2.5	81.8	73.2	82.4	1	1	2	6	0	0	10	1	2
2/25	08.7°S	139.3°W	0000	99	07	09	02	0	1010.2	6	1.5	85.0	74.5	83.0	1	1	2	6	0	0	09	1	2
2/25	09.2°S	139.2°W	1800	97	13	10	14	2	1012.5	2	2.0	78.9	75.5	82.1	7	5	7	4	0	2	15	1	2
2/26	09.8°S	138.8°W	0000	98	07	10	14	2	1009.1	7	2.5	82.6	76.4	82.6	4	3	2	5	0	2	10	1	2
2/26	10.1°S	138.8°W	1800	99	06	12	01	0	1012.9	2	1.5	83.6	73.8	82.0	1	1	2	6	0	0	10	1	2
2/27	10.6°S	138.7°W	0000	99	06	10	03	0	1009.8	7	2.0	83.4	75.5	82.9	2	2	2	6	0	0	10	1	2
2/27	10.2°S	139.0°W	1800	99	08	13	03	0	1013.2	1	2.0	82.2	75.3	82.7	3	3	2	5	0	0	08	1	2
2/28	09.8°S	139.2°W	0000	99	04	13	02	0	1010.2	6	2.0	83.5	74.5	83.0	2	2	2	5	0	0	06	1	2
2/28	09.8°S	139.4°W	1800	99	07	14	02	0	1013.9	2	2.0	82.5	74.2	82.5	1	1	2	6	0	0	02	1	2
3/1	09.5°S	140.2°W	0000	99	06	03	02	0	1009.1	7	3.0	84.2	74.0	83.3	1	1	2	6	0	0	02	1	2
3/3	08.9°S	139.7°W	1800	99	11	14	01	0	1013.5	1	1.0	83.4	73.4	82.5	2	2	2	4	0	0	06	2	1
3/4	08.9°S	139.7°W	0000	99	11	16	15	0	1009.5	6	2.5	82.0	76.4	82.3	3	2	2	4	7	0	05	2	1
3/4	06.8°S	139.7°W	1200	98	09	16	00	0	1009.5	6	1.5	80.6	75.4	80.6	2	2	2	4	0	0	08	2	1
3/4	06.2°S	139.7°W	1800	99	09	16	01	0	1011.5	X	XX	81.0	75.3	80.5	3	3	4	4	0	0	08	2	2
3/5	05.4°S	139.7°W	0000	99	11	12	01	0	1007.5	7	2.5	81.0	74.7	80.6	1	0	0	9	1	0	08	2	2
3/5	05.5°S	139.7°W	0600	99	12	17	00	0	1010.5	2	2.5	80.5	74.9	79.8	1	1	1	4	0	0	08	2	2
3/5	06.0°S	139.7°W	1200	98	10	18	00	0	1009.1	6	1.5	80.0	74.7	80.0	1	1	1	4	0	0	07	2	2
3/5	06.8°S	139.8°W	1800	98	10	11	03	1	1011.9	1	1.5	80.1	76.0	80.2	5	4	8	4	4	0	07	2	2
3/6	07.5°S	139.7°W	0000	99	09	11	01	1	1008.1	7	3.0	83.0	77.0	82.5	3	3	2	4	0	0	07	2	2
3/6	08.2°S	139.8°W	0600	98	10	16	00	0	1010.5	1	2.0	82.1	75.0	81.7	2	2	1	4	0	0	10	2	1
3/8	09.7°S	139.7°W	1800	99	07	15	00	0	1010.8	2	1.5	82.8	76.3	82.0	2	2	2	4	0	0	10	2	1
3/9	10.1°S	139.6°W	0000	99	10	15	01	0	1008.1	7	2.0	83.2	75.0	82.5	1	1	2	4	0	0	09	2	1
3/9	10.8°S	139.6°W	0600	98	10	15	00	0	1010.8	2	2.0	82.9	75.2	82.8	2	2	1	4	0	0	14	1	1
3/9	11.3°S	139.7°W	1200	98	11	14	00	0	1009.5	6	1.5	81.0	76.2	82.6	4	4	1	4	0	0	14	1	1
3/9	12.2°S	139.7°W	1800	98	08	15	50	1	1011.5	1	2.0	82.8	76.3	83.0	6	5	2	4	4	0	14	1	1
3/10	12.8°S	139.7°W	0000	99	09	10	02	5	1009.1	7	2.0	83.8	77.0	82.9	3	3	2	4	0	0	09	2	2
3/10	12.8°S	139.8°W	0600	98	08	11	01	0	1011.5	2	2.0	83.1	76.4	83.0	2	2	2	4	0	0	09	2	1
3/10	12.1°S	139.7°W	1200	98	08	11	02	0	1009.8	7	2.0	82.0	74.3	82.5	2	2	2	4	0	0	07	2	1
3/10	10.3°S	139.7°W	1800	99	10	07	02	0	1012.2	2	2.0	82.6	74.9	82.8	1	1	3	5	0	0	06	3	1
3/11	10.0°S	139.4°W	0600	99	09	16	00	0	1010.8	2	2.0	82.9	76.0	83.3	1	1	2	4	0	0	07	2	1
3/17	08.6°S	140.6°W	0000	98	08	12	01	1	1011.2	7	2.0	83.5	77.5	83.6	4	4	4	4	0	0	06	2	1
3/17	07.6°S	141.0°W	0600	98	10	12	02	0	1013.2	2	2.0	82.8	76.6	82.3	2	2	2	4	0	0	06	2	1
3/17	06.8°S	141.4°W	1200	98	07	14	01	0	1012.2	6	1.5	81.4	76.5	82.0	1	2	2	4	0	0	09	2	1
3/17	06.1°S	142.0°W	1800	98	09	17	01	0	1015.2	2	2.0	81.9	76.2	81.3	1	1	2	4	0	0	05	2	1
3/18	05.2°S	142.4°W	0000	98	06	11	03	0	1011.9	7	3.0	81.6	75.2	82.0	4	3	2	4	1	0	03	2	1

Table 3.--Weather observations, Charles H. Gilbert cruise 43 - continued

Date, 1959	Latitude	Longitude	Time, GCT	Visibility	Wind		Weather		Pressure			Temperature			Clouds						Waves		
					Direction	Speed, kt.	Present	Past	Bar. corr., mb.	Characteristic	Amt. change	Dry bulb, °F.	Wet bulb, °F.	Sea water, °F.	Total amount	Amount low	Type low	Height low	Type middle	Type high	Direction	Period	Height
3/18	04.2°S	143.3°W	0600	98	09	13	02	0	1013.5	2	2.5	81.1	75.0	81.1	2	2	2	4	0	0	05	2	1
3/18	03.7°S	143.7°W	1200	98	08	07	03	0	1012.5	7	1.5	79.5	73.9	81.0	3	3	2	4	0	0	05	1	1
3/18	03.0°S	144.0°W	1800	98	11	11	02	0	1014.2	1	1.5	80.4	74.8	80.6	2	2	2	4	0	0	04	1	1
3/19	02.4°S	144.5°W	0000	98	16	11	03	0	1010.2	7	2.5	81.2	75.2	81.9	4	4	2	4	0	0	16	2	1
3/19	02.1°S	144.6°W	0600	98	12	11	02	0	1013.2	2	3.0	81.0	76.0	81.1	2	2	2	4	0	0	05	1	1
3/19	01.5°S	144.7°W	1200	98	11	09	01	0	1011.9	7	2.0	80.5	75.9	80.6	2	2	2	4	0	0	05	1	1
3/19	00.5°S	145.5°W	1800	99	18	11	02	0	1014.6	1	2.0	83.2	76.8	80.5	2	2	2	4	0	0	10	1	1
3/20	00.3°N	145.9°W	0000	98	17	12	03	0	1010.5	7	2.5	85.0	78.1	81.3	3	2	2	4	5	0	16	2	1
3/20	01.2°N	146.4°W	0600	97	11	08	03	1	1013.2	2	2.5	81.5	76.7	80.7	7	3	2	4	5	1	12	1	1
3/20	02.2°N	146.8°W	1200	97	11	12	00	2	1010.5	7	2.0	80.2	76.4	81.0	7	2	2	4	5	0	12	2	1
3/20	03.0°N	147.3°W	1800	99	10	09	01	1	1012.9	2	2.0	82.1	77.0	81.1	3	2	2	4	4	1	12	1	1
3/21	03.8°N	147.8°W	0000	98	08	09	01	1	1010.2	7	2.0	81.8	76.4	82.5	4	2	4	4	5	0	04	1	1
3/21	04.9°N	148.1°W	0600	98	08	12	02	1	1012.5	2	2.0	82.0	77.1	82.2	3	2	2	5	3	0	04	1	1
3/21	05.6°N	148.5°W	1200	98	07	18	16	1	1010.2	2	2.0	80.1	77.0	82.0	4	2	2	4	5	0	04	2	2
3/21	06.6°N	148.9°W	1800	97	05	15	63	6	1013.2	2	2.5	80.9	77.3	81.5	8	8	4	3	X	X	04	2	2
3/22	07.3°N	149.3°W	0000	97	08	23	14	6	1009.5	8	3.5	81.3	76.9	82.0	8	8	4	3	X	X	04	2	3
3/22	08.1°N	149.2°W	0600	96	07	20	01	6	1011.9	2	1.0	81.8	76.6	80.9	7	X	X	X	3	X	04	2	3
3/22	08.9°N	149.6°W	1200	96	06	19	00	2	1010.5	7	2.0	80.7	75.7	81.0	6	5	2	4	3	0	04	2	3
3/22	09.7°N	150.1°W	1800	98	06	20	21	2	1013.2	2	2.0	80.0	76.3	79.2	6	6	4	4	0	0	04	2	3
3/23	10.6°N	150.5°W	0000	98	07	21	00	2	1010.8	7	2.5	80.0	74.7	80.0	7	4	4	4	5	0	04	2	3
3/23	12.5°N	150.8°W	0600	96	06	23	00	2	1013.2	2	2.0	78.2	74.5	78.5	7	6	4	4	0	0	06	2	3
3/23	12.3°N	151.1°W	1200	96	07	20	00	2	1012.9	7	2.0	77.3	73.1	77.6	6	6	4	4	0	0	06	2	3
3/23	13.1°N	151.8°W	1800	97	06	24	14	5	1015.2	2	3.0	77.0	72.0	77.4	7	7	7	4	0	0	06	2	3
3/24	14.0°N	152.3°W	0000	98	07	20	03	1	1013.9	7	2.0	78.0	72.0	77.4	4	4	1	4	0	0	06	2	3
3/24	14.7°N	152.6°W	0600	96	07	24	02	2	1016.9	2	3.0	76.5	71.6	75.5	7	7	2	4	0	0	06	2	3
3/24	15.5°N	153.1°W	1200	97	07	15	03	1	1017.6	7	1.5	75.3	69.5	76.0	7	7	2	4	0	0	06	2	3
3/24	16.5°N	153.4°W	1800	98	07	22	01	0	1019.3	2	2.0	75.8	70.5	75.6	2	2	2	4	0	0	06	2	3
3/25	17.0°N	153.7°W	0000	98	07	22	02	2	1018.6	7	1.5	74.8	69.9	76.2	6	6	4	4	0	0	07	2	3
3/25	17.2°N	153.9°W	0600	97	08	20	02	2	1019.6	3	2.0	76.3	70.1	76.2	7	7	2	4	0	0	06	2	3
3/25	17.7°N	154.5°W	1200	98	08	23	01	1	1019.6	7	1.5	74.8	69.9	75.1	2	2	2	4	0	0	06	2	3
3/25	18.2°N	155.4°W	1800	98	06	24	02	0	1020.7	2	2.0	74.8	70.5	73.9	2	2	2	4	0	0	07	2	3
3/26	18.8°N	156.0°W	0000	98	08	20	01	0	1019.0	7	2.5	75.1	71.0	76.1	2	2	2	4	0	0	07	2	3

Table 4.--Temperature and salinity of surface water in baiting areas, *Charles H. Gilbert* cruise 43

Date, 1959	Time, LT	Locality	Salinity ‰	Temp., °F.
1/22	1020	Tai Oa, Nuku Hiva	35.44	84.9
1/22	1420	Taipi Vai, Nuku Hiva	12.70	79.4
1/24	0817	Taipi Vai, Nuku Hiva	34.79	81.1
1/25	0625	Taiohae, Nuku Hiva	35.97	81.5
2/10	0625	Tautira, Tahiti	17.05	78.0
2/19	1242	Taipi Vai, Nuku Hiva	28.05	83.1
2/20	0655	Tai Oa, Nuku Hiva	35.77	81.4
2/20	0915	Tai Oa, Nuku Hiva	31.48	76.9
2/20	1345	Taiohae, Nuku Hiva	35.96	84.2
3/1	1231	Taipi Vai, Nuku Hiva	25.35	82.0
3/2	0516	Taiohae, Nuku Hiva	35.92	81.5
3/2	0953	Taiohae, Nuku Hiva	35.91	84.6
3/6	1000	Taipi Vai, Nuku Hiva	33.15	85.0
3/14	1340	Taiohae, Nuku Hiva	36.04	87.8

Table 5.--Transparency, water color and related observations, *Charles H. Gilbert* cruise 43

Date, 1959	Noon position 1/		Secchi disc, meters	Water color (Forel)	Sea 2/	Wind 3/	Percent sky cover
	Latitude	Longitude					
1/27	14°10'S	141°27'W	33.0	1	3	- 18	80
1/28	15°53'S	142°05'W	40.2	2	2	- 16	70
1/29	16°32'S	143°08'W	39.4	2	2	08 - 14	50
1/30	16°08'S	144°28'W	36.6	2	1	- 07	80
1/31	15°54'S	145°40'W	47.6	1	1	- 08	30
2/1	15°31'S	146°08'W	40.2	1	1	- 06	20
2/2	15°16'S	147°09'W	38.4	1	0	29 - 08	30
2/22	08°38'S	140°26'W	20.6	2	1	04 - 10	70
2/23	07°53'S	139°59'W	27.0	1	1	07 - 11	20
2/24	08°43'S	139°13'W	28.4	1	1	08 - 13	20
2/25	09°35'S	138°50'W	22.8	1	1	09 - 12	70
2/26	10°22'S	138°26'W	38.9	1	1	08 - 13	10
2/27	09°49'S	139°09'W	22.0	1	1	34 - 03	30
2/28	09°33'S	140°02'W	34.8	1	1	08 - 15	10

1/ All observations taken at 1200 LT, except on 2/28 when the observation was taken at 1300 LT.

2/ Sea state coded according to H.O. Pub. No. 606-c, second edition, 1956.

3/ Wind direction and speed coded according to U.S. Weather Bureau, Circular M.

Table 6.--Surface troll catch and related data, *Charles H. Gilbert* cruise 43

Date 1959	Time, LT	Position		Species	Number[1]	Average length, cm.
		Latitude	Longitude			
1/9	1635	17°58'N	155°16'W	Yellowfin	3	77.0
1/9	1700	17°56'N	155°14'W	Dolphin	4	67.0
1/9	1715	17°54'N	155°13'W	Bigeye	2	45.5
1/10	0850	15°57'N	154°04'W	Dolphin	1	88.0
1/10	1000	15°49'N	153°58'W	Dolphin	3	78.7
1/11	1000	15°49'N	153°58'W	Dolphin	1	78.7
1/21	1600	09°23'S	140°08'W	Dolphin	1	103.0
2/18	1145	10°14'S	142°26'W	Rainbow Runner	1	72.2
2/23	0610	07°55'S	140°38'W	Little Tuna	1	61.3
2/23	0620	07°54'S	140°36'W	Yellowfin	2	85.8
2/23	0710	07°50'S	140°32'W	Wahoo	1	85.8
2/23	1215	07°54'S	139°57'W	Yellowfin	2	83.4
2/25	0525	08°59'S	139°30'W	Yellowfin	1	91.9
2/25	0530	09°00'S	139°30'W	Little Tuna	3	52.3
2/26	0830	10°08'S	138°46'W	Wahoo	1	115.5
2/26	1220	10°24'S	138°27'W	Wahoo	1	148.9
3/5	1730	07°53'S	139°43'W	Barracuda	1	138.1
3/8	0555	09°10'S	139°38'W	Dolphin	1	116.1
3/13	1300	08°48'S	139°46'W	Little Tuna	1	49.1
3/14	0630	08°46'S	140°04'W	Yellowfin	3	75.3
3/14	0700	08°36'S	139°59'W	Little Tuna	1	47.5
3/14	0700	08°36'S	139°59'W	Wahoo	1	136.9
3/16	1115	08°56'S	140°14'W	Wahoo	2	130.3

[1] Fish of the same species caught within a 1-hour interval were combined in a single number.

Table 7.--Surface troll catch, Cape Falcon

Date, 1959	Yellowfin	Skipjack	Little tuna	Rainbow runner	Wahoo	Barracuda	Dogtooth tuna	Jack	Green Snapper
2/17	1	-	-	-	-	-	-	-	-
2/18	13	8	8	1	-	1	-	-	-
2/19	11	1	3	2	-	-	-	1	-
2/20	12	-	-	-	-	-	1	-	-
2/21	4	2	-	-	-	-	-	-	-
2/22	2	4	-	1	1	-	-	-	-
2/23	2	-	-	-	-	-	-	-	-
2/24	2	-	-	-	-	-	-	-	-
2/25	-	1	-	-	-	-	-	-	-
2/26	1	1	-	-	-	-	-	-	-
2/27	-	1	-	-	-	-	-	-	-
3/2	-	2	-	-	-	-	-	-	-
3/3	-	1	-	-	-	-	-	-	-
3/4	2	-	-	-	-	-	-	-	-
3/5	15	-	1	-	3	-	1	-	3
3/6	11	1	1	-	-	-	-	-	-
3/7	11	1	5	1	1	-	-	4	-
3/10	13	-	-	-	1	-	-	-	-
3/11	2	2	-	1	-	-	-	-	-
3/12	6	-	-	-	1	-	-	-	-
3/13	26	-	3	-	-	-	-	-	-
3/14	2	2	2	-	-	-	-	-	-
Total	136	27	23	6	7	1	2	5	3

Table 8.--Summary of pole-and-line fishing, Charles H. Gilbert cruise 43

Date, 1959	Time, LT	Position		Number of passes	Number of minutes chummed	Number caught and species[1]	Amount of bait (buckets)
		Latitude	Longitude				
1/15	1112	02°02'N	145°10'W	1	3	0 SJ	1.0[2]
1/29	0953	16°25'S	142°59'W	1	5	0 SJ	.5
1/29	1016	16°28'S	143°02'W	3	8	1 SJ	4.0
1/29	1350	16°35'S	143°28'W	2	16	166 SJ	7.0
1/30	1410	16°01'S	144°49'W	1	2	0 SJ	1.0
1/31	0745	15°45'S	145°06'W	1	6	40 SJ	2.0
1/31	1345	15°54'S	145°40'W	2	5	0 SJ	.5
2/1	1105	15°29'S	146°06'W	1	11	217 SJ	5.0
2/2	0643	15°30'S	146°36'W	2	8	17 SJ, 4 YF	4.0
2/2	0855	15°25'S	146°49'W	1	3	0 SJ	.5
2/2	0955	15°21'S	146°57'W	1	2	0 SJ	.5
2/4	1520	14°58'S	147°31'W	2	6	0 SJ	1.0
2/22	1217	08°36'S	140°28'W	2	6	102 SJ	2.0
2/23	0831	07°45'S	140°20'W	4	10	0 SJ	2.0
2/23	0925	07°44'S	140°16'W	5	6	0 YF	2.0
2/23	1337	08°01'S	139°45'W	1	3	41 SJ	2.0
2/23	1445	08°05'S	139°39'W	2	7	16 SJ, 48 YF	2.0
2/24	0925	08°33'S	139°15'W	4	9	13 SJ	2.0
2/24	1012	08°36'S	139°13'W	2	4	0 SJ	1.0
2/24	1110	08°42'S	139°11'W	2	5	0 SJ	1.0
2/24	1245	08°47'S	139°16'W	1	4	0 SJ	1.0
2/25	0824	09°15'S	139°12'W	2	4	0 SJ	1.0
2/25	1310	09°44'S	138°46'W	2	7	0 SJ	1.0
2/25	1550	09°50'S	138°59'W	2	3	0 UN	1.0
2/26	0940	10°13'S	138°33'W	2	5	85 SJ	2.0
2/26	1215	10°24'S	138°28'W	2	4	0 SJ	1.0
2/27	1204	09°49'S	139°13'W	9	15	82 SJ	6.0
2/27	1333	09°51'S	139°15'W	3	12	0 SJ	2.0
2/28	1145	09°32'S	140°02'W	6	14	92 SJ	6.0
3/3	0815	08°50'S	139°40'W	3	9	17 SJ, 2 YF	5.0
3/5	1003	07°07'S	139°46'W	1	6	42 SJ	3.0
3/5	1253	07°21'S	139°44'W	2	11	231 SJ	4.0
3/8	1003	09°40'S	139°36'W	1	8	195 SJ	3.0
3/8	1058	10°47'S	139°35'W	3	13	23 SJ, 26 YF, 2 BE	3.0
3/8	1216	09°56'S	139°36'W	1	5	25 SJ	2.0
3/10	1306	10°44'S	139°37'W	2	8	0 SJ	2.0
3/10	1415	10°40'S	139°38'W	2	5	25 SJ	2.0

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[1] SJ = skipjack, YF = yellowfin, BE = bigeye, UN = unidentified

[2] Tilapia; Marquesan sardines were used at all other occasions.

Table 9. --Summary of pole-and-line fishing, *Cape Falcon*

Date, 1959	Time, LT	Position		Number of passes	Number of minutes chummed	Number caught and species 1/	Amount of bait, (scoops) 2/
		Latitude	Longitude				
2/16	0728	06°10'S	133°34'W	1	1.0	0 SJ	.50
2/17	1034	07°24'S	137°28'W	1	2.0	0 YF	.25
2/17	1151	07°24'S	137°34'W	2	6.0	81 SJ	10.00
2/17	1519	07°28'S	138°05'W	5	8.0	0 SJ	2.00
2/18	0617	07°55'S	139°58'W	4	30.0	56 YF	20.00
2/18	0821	07°55'S	139°58'W	1	19.0	210 YF	20.00
2/18	0850	07°55'S	139°58'W	1	.5	0 YF	handful
2/18	0854	07°55'S	139°58'W	3	4.0	0 SJ	2.50
2/18	0945	07°55'S	139°58'W	1	1.0	0 UN	.50
2/18	0956	07°55'S	139°58'W	1	9.0	42 YF	8.00
2/18	1027	07°55'S	139°58'W	1	4.0	5 YF	2.00
2/18	1044	07°55'S	139°58'W	1	1.0	0 UN	.50
2/18	1124	07°55'S	139°58'W	2	2.0	0 SJ	1.00
2/18	1306	07°55'S	139°58'W	3	29.0	69 YF	19.00
2/18	1410	07°55'S	139°58'W	7	26.5	148 YF	21.00
2/18	1520	07°55'S	139°58'W	4	7.5	86 YF, 0 SJ	7.25
2/18	1600	07°55'S	139°58'W	1	4.0	50 YF	5.00
2/18	1628	07°55'S	139°58'W	2	2.0	0 UN	.75
2/18	1639	07°55'S	139°58'W	1	1.0	0 SJ	1.00
2/18	1750	07°55'S	139°58'W	4	7.0	7 YF, 0 SJ	6.00
2/19	0659	07°55'S	139°58'W	4	18.0	37 YF	7.00
2/19	0817	07°55'S	139°58'W	2	8.0	6 YF, 0 SJ	9.00
2/19	0952	07°54'S	140°12'W	2	6.0	4 YF	3.00
2/19	1025	07°54'S	140°13'W	2	9.0	18 YF	4.50
2/19	1215	07°54'S	140°21'W	1	1.0	0 UN	.50
2/19	1412	07°54'S	140°32'W	3	9.0	25 YF	7.25
2/19	1500	07°54'S	140°31'W	2	8.5	45 YF, 2 RR	7.00
2/19	1522	07°53'S	140°31'W	1	1.0	0 SJ	.50
2/19	1545	07°54'S	140°32'W	4	17.0	88 YF, 0 SJ	12.50
2/19	1642	07°52'S	140°34'W	1	2.0	0 YF	1.00
2/19	1647	07°53'S	140°34'W	1	2.0	0 UN	1.00
2/19	1700	07°54'S	140°34'W	4	6.0	1 YF, 0 SJ	3.50
2/19	1736	07°54'S	140°34'W	2	5.0	7 YF, 0 LT	4.00
2/20	0707	07°56'S	140°36'W	1	2.0	0 YF	.50
2/20	0721	07°56'S	140°37'W	1	4.0	5 YF	4.00
2/20	0754	07°54'S	140°38'W	2	6.0	5 YF	5.50
2/20	0920	07°53'S	140°37'W	2	5.0	0 YF, 0 LT	1.50
2/20	0937	07°53'S	140°37'W	1	1.0	0 SJ	.50
2/20	0954	07°53'S	140°37'W	3	3.0	0 YF, 0 UN	1.50
2/20	1037	07°57'S	140°39'W	2	2.0	0 SJ	1.00
2/20	1153	08°04'S	140°46'W	1	17.0	67 YF	20.00
2/20	1236	08°02'S	140°45'W	2	6.0	25 YF	12.00
2/20	1325	08°04'S	140°43'W	1	1.0	0 SJ	.50
2/20	1345	08°04'S	140°45'W	1	.5	0 SJ	.50
2/20	1405	08°05'S	140°46'W	3	5.0	4 YF, 0 SJ	4.00
2/20	1435	08°04'S	140°45'W	1	1.0	0 SJ	1.00

1/ SJ = skipjack, YF = yellowfin, LT = little tuna, UN = unidentified, RR = rainbow runner

2/ In converting "scoops" to weight, Alverson and Shimada (1957) used a factor of 8 pounds per scoop.

Table 9.--Summary of pole-and-line fishing, Cape Falcon - continued

Date, 1959	Time, LT	Position		Number of passes	Number of minutes chummed	Number caught and species 1/	Amount of bait, (scoops)2/
		Latitude	Longitude				
2/20	1455	08°03'S	140°44'W	3	3.0	0 YF	1.50
2/21	1029	08°30'S	140°03'W	1	2.0	0 SJ	1.00
2/21	1140	08°27'S	140°03'W	2	3.0	0 SJ	2.00
2/21	1223	08°39'S	140°02'W	3	4.0	0 YF	2.00
2/22	1010	09°15'S	140°02'W	1	1.0	0 SJ	2.00
2/22	1134	09°21'S	139°59'W	1	2.0	14 YF	5.00
2/22	1156	09°23'S	139°59'W	1	3.0	0 YF	1.00
2/22	1210	09°25'S	140°00'W	1	1.0	0 UN	1.00
2/22	1334	09°34'S	140°04'W	1	2.0	0 SJ	1.00
2/22	1403	09°40'S	140°05'W	2	2.0	0 SJ	2.00
2/22	1500	09°50'S	140°08'W	1	1.0	0 SJ	1.00
2/24	1553	14°08'S	140°27'W	2	5.0	0 YF	2.00
2/24	1614	14°09'S	140°28'W	1	2.0	0 UN	1.00
2/25	0917	16°04'S	142°30'W	2	2.0	0 UN	3.00
2/26	1443	16°57'S	144°33'W	1	2.0	0 SJ	2.00
2/27	1158	17°13'S	147°34'W	1	1.0	0 SJ	7.00
2/27	1338	17°17'S	147°52'W	3	4.5	0 SJ	1.00
3/2	0925	15°13'S	146°49'W	1	1.0	0 UN	1.00
3/2	1358	14°43'S	146°27'W	2	3.0	0 SJ	6.00
3/2	1702	14°30'S	146°15'W	1	3.0	0 SJ	3.00
3/4	1109	10°32'S	142°24'W	1	1.0	0 YF	2.00
3/5	0638	08°42'S	140°37'W	1	2.0	0 YF	2.00
3/5	0645	08°42'S	140°37'W	1	3.0	1 YF	3.00
3/5	0657	08°41'S	140°37'W	1	1.0	0 YF, 0 DT	1.00
3/5	0749	08°40'S	140°36'W	1	4.0	2 YF	3.00
3/5	0807	08°37'S	140°37'W	2	3.0	0 YF, 0 SJ	4.00
3/5	0929	08°40'S	140°39'W	1	1.0	0 SJ	1.00
3/5	0958	08°41'S	140°38'W	1	1.0	0 YF, 0 RR	2.00
3/5	1518	08°12'S	140°36'W	1	1.0	0 YF	2.00
3/6	0611	08°02'S	140°43'W	1	3.0	0 YF	2.00
3/6	0618	08°02'S	140°43'W	1	3.0	0 YF	2.00
3/6	1117	07°58'S	140°07'W	1	1.0	0 YF	2.00
3/6	1209	07°56'S	140°02'W	2	2.0	0 SJ	2.50
3/6	1422	07°55'S	139°58'W	1	-	0 UN	1.00
3/6	1544	07°52'S	139°56'W	1	1.0	0 YF	2.00
3/6	1626	07°55'S	139°58'W	2	3.0	0 YF	3.00
3/7	0628	07°55'S	139°58'W	1	1.0	0 YF, 0 UN	3.00
3/7	0652	07°55'S	139°58'W	1	3.0	0 YF, 0 LT, 0 RR	2.00
3/7	0718	07°55'S	139°58'W	2	2.0	0 SJ	5.00
3/7	0802	07°57'S	139°56'W	1	2.0	0 YF	2.00
3/7	0930	07°59'S	139°42'W	1	2.0	0 YF	4.00
3/7	1220	08°05'S	139°38'W	1	3.0	15 YF, 0 UN	10.00
3/7	1247	08°05'S	139°38'W	1	1.0	0 LT, 0 RR	3.00
3/7	1404	08°08'S	139°31'W	5	11.0	11 YF	18.00
3/7	1607	08°16'S	139°26'W	1	1.0	0 SJ	3.00

1/ SJ = skipjack, YF = yellowfin, LT = little tuna, UN = unidentified, DT = dogtooth tuna, RR = rainbow runner

2/ In converting "scoops" to weight, Alverson and Shimada (1957) used a factor of 8 pounds per scoop.

Table 9. --Summary of pole-and-line fishing, *Cape Falcon* - continued

Date, 1959	Time, LT	Position		Number of passes	Number of minutes chummed	Number caught and species [1]	Amount of bait, (scoops)[2]
		Latitude	Longitude				
3/7	1639	08°18'S	139°24'W	1	4.0	0 SJ	5.00
3/10	0555	08°48'S	140°07'W	2	3.0	0 YF	4.00
3/10	0712	08°48'S	140°15'W	3	3.0	0 YF	5.00
3/10	0732	08°48'S	140°16'W	1	1.0	0 YF	1.00
3/10	1132	08°56'S	139°59'W	1	1.0	0 UN	3.00
3/11	1515	09°00'S	139°38'W	2	2.0	0 SJ, 0 RR	3.00
3/11	1600	09°00'S	139°38'W	1	2.0	0 SJ	3.00
3/11	1715	08°58'S	139°39'W	1	1.0	0 YF	2.00
3/12	0740	08°01'S	139°28'W	1	1.0	0 SJ	.50
3/12	1247	08°41'S	139°17'W	1	2.0	0 UN	1.00
3/12	1620	08°15'S	139°32'W	2	3.0	13 YF, 0 SJ	5.50
3/12	1655	08°15'S	139°32'W	1	1.0	0 SJ	1.00
3/13	0555	08°20'S	139°37'W	2	3.0	5 YF	5.00
3/13	0909	08°02'S	139°45'W	2	3.0	0 YF	3.00
3/13	0950	08°01'S	139°43'W	1	2.0	0 YF	1.00
3/13	1152	07°52'S	139°59'W	1	1.0	0 YF, 0 RR	1.00
3/13	1214	07°52'S	139°59'W	1	4.0	2 YF	2.00
3/13	1303	07°52'S	139°59'W	3	3.0	0 YF	2.00
3/13	1422	07°56'S	140°00'W	1	5.0	2 YF, 0 LT	4.00
3/13	1445	07°53'S	139°59'W	1	2.0	0 YF	1.00
3/13	1525	07°56'S	140°00'W	1	3.0	2 YF	2.00
3/13	1534	07°56'S	139°58'W	1	2.0	0 YF	1.00
3/13	1610	07°56'S	139°58'W	1	1.0	0 YF	1.00
3/13	1655	07°56'S	140°00'W	1	1.0	0 YF	.50
3/14	0634	07°56'S	139°57'W	4	4.0	0 YF, 0 SJ	2.50

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[1] SJ = skipjack, YF = yellowfin, LT = little tuna, UN = unidentified, RR = rainbow runner.

[2] In converting "scoops" to weight, Alverson and Shimada (1957) used a factor of 8 pounds per scoop.

Table 10.--Pole-and-line caught skipjack, yellowfin, and bigeye length frequency distribution, Charles H. Gilbert cruise 43

Date, 1959	Latitude and Longitude	Sex	Species[1]	Fork length range in millimeters																																					Total
				415-424	425-434	435-444	445-454	455-464	465-474	475-484	485-494	495-504	505-514	515-524	525-534	535-544	545-554	555-564	565-574	575-584	585-594	595-604	605-614	615-624	625-634	635-644	645-654	655-664	665-674	675-684	685-694	695-704	705-714	715-724	725-734	735-744	745-754	755-764	765-774	775-784	
1/29	16°28'S	M	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	143°02'W	F	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
1/29	16°35'S	M	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	3	2	1	3	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
	143°28'W	F	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	2	3	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
1/31	15°45'S	M	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	6	2	1	1	-	-	-	-	-	-	12
	145°06'W	F	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	1	6	2	-	1	-	-	-	-	-	13
2/1	15°29'S	M	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	4	1	3	2	-	-	-	-	-	-	-	-	-	-	13
	146°06'W	F	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	2	4	2	-	-	-	-	1	-	-	-	-	-	12
2/2	15°30'S	M	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	2	7	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12
	146°36'W	F	SJ	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
		?	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	4
2/22	08°36'S	M	SJ	-	-	-	-	-	-	-	-	1	1	1	2	4	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12
	140°28'W	F	SJ	-	-	-	-	-	-	3	2	-	4	-	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13
2/23	08°01'S	M	SJ	-	-	-	-	-	1	2	1	3	3	2	1	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17
	139°45'W	F	SJ	-	-	-	-	-	-	-	3	1	1	2	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
2/23	08°05'S	M	SJ	-	-	-	-	-	-	-	-	-	2	2	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
	139°39'W	F	SJ	-	-	-	-	-	-	-	1	2	-	1	3	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
		?	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	1	-	1	2	1	2	3	3	3	4	1	1	-	1	25
2/24	08°33'S	M	SJ	-	-	-	-	-	-	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
	139°15'W	F	SJ	-	-	-	1	-	-	3	1	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
2/26	10°13'S	M	SJ	1	3	3	4	2	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
	138°33'W	F	SJ	-	2	-	3	1	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
2/27	09°49'S	M	SJ	-	-	-	-	-	-	-	-	2	-	3	8	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18
	139°13'W	F	SJ	-	-	-	-	-	-	-	-	1	2	2	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
2/28	09°32'S	M	SJ	-	-	-	-	1	2	4	3	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14
	140°02'W	F	SJ	-	-	-	-	1	2	5	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
3/3	08°50'S	M	SJ	1	1	5	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
	139°40'W	F	SJ	-	1	1	-	1	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
		?	YF	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2

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[1] SJ = Skipjack, YF = Yellowfin, BE = Bigeye

Table 10.--Pole-and-line caught skipjack, yellowfin, and bigeye length frequency distribution, Charles H. Gilbert cruise 43 - continued

Date, 1959	Latitude and Longitude	Sex	Species[1]	Fork length range in millimeters																																					Total
				415-424	425-434	435-444	445-454	455-464	465-474	475-484	485-494	495-504	505-514	515-524	525-534	535-544	545-554	555-564	565-574	575-584	585-594	595-604	605-614	615-624	625-634	635-644	645-654	655-664	665-674	675-684	685-694	695-704	705-714	715-724	725-734	735-744	745-754	755-764	765-774	775-784	
3/5	07°07'S	M	SJ	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	2	3	2	1	1	-	1	-	-	-	-	-	-	13
	139°46'W	F	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	4	3	1	-	-	-	-	1	-	-	-	-	12
3/5	07°21'S	M	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	2	1	3	1	2	1	1	-	-	-	-	-	-	-	1	-	-	15
	139°44'W	F	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	2	3	2	1	3	1	-	-	-	-	-	-	-	-	-	-	-	14
3/8	09°40'S	M	SJ	-	-	6	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
	139°36'W	F	SJ	-	-	2	2	3	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
3/8	10°47'S	M	SJ	-	1	-	-	-	2	2	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
	139°35'W	F	SJ	-	-	1	-	-	4	4	3	-	-	-	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
		?	YF	-	-	-	-	-	-	-	2	3	12	6	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27
		?	BE	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
3/8	09°56'S	M	SJ	-	-	-	-	1	-	-	-	-	1	1	4	4	2	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
	139°36'W	F	SJ	-	-	-	-	-	-	-	1	2	1	2	2	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
3/10	10°40'S	M	SJ	-	-	-	2	1	-	4	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13
	139°38'W	F	SJ	-	-	-	-	3	3	1	2	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12
Total			SJ	2	8	18	13	26	21	34	28	21	19	16	27	22	15	12	5	8	6	7	6	4	6	13	11	10	17	15	9	9	3	2	2	1	-	1	-	-	417
			YF	-	-	-	-	-	-	-	2	3	12	6	2	3	1	-	-	-	-	2	-	-	2	-	3	-	1	2	1	2	3	3	3	4	1	1	-	1	58
			BE	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2

[1] SJ = Skipjack, YF = Yellowfin, BE = Bigeye

Table 11. --Pole-and-line caught skipjack and yellowfin length frequency distribution, Cape Falcon

Date, 1959	Latitude and Longitude	Species[1]	Fork Length range in millimeters																																																																					Total
			525-534	535-544	545-554	555-564	565-574	575-584	585-594	595-604	605-614	615-624	625-634	635-644	645-654	655-664	665-674	675-684	685-694	695-704	705-714	715-724	725-734	735-744	745-754	755-764	765-774	775-784	785-794	795-804	805-814	815-824	825-834	835-844	845-854	855-864	865-874	875-884	885-894	895-904	905-914	915-924	925-934	935-944	945-954	955-964	965-974	975-984	985-994	995-1004	1005-1014	1015-1024	1025-1034	1035-1044	1045-1054	1055-1064	1065-1074	1075-1084	1085-1094	1095-1104	1105-1114	1115-1124	1125-1134	1135-1144	1145-1154	1155-1164	1165-1174	1175-1184	1185-1194	1195-1204	1205-1214	1275-1284	1405-1414	
2/17	07°24'S 137°34'W	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	1	3	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
2/18	07°55'S 139°58'W	YF	1	-	-	-	-	1	-	-	-	-	-	-	-	1	2	1	-	1	2	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-	2	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	2	21
2/18	07°55'S 139°58'W	YF	-	-	-	-	-	-	-	-	1	1	-	-	1	-	2	1	-	2	1	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
2/18	07°55'S 139°58'W	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	1	-	-	2	-	1	-	-	-	-	-	-	6
2/18	07°55'S 139°58'W	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
2/18	07°55'S 139°58'W	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	1	-	-	-	1	1	-	-	-	1	-	-	-	-	-	7
2/18	07°55'S 139°58'W	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
2/18	07°55'S 139°58'W	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	2	-	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
2/18	07°55'S 139°58'W	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	2	-	1	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
2/19	07°55'S 139°58'W	YF	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
2/19	07°55'S 139°58'W	YF	-	1	-	-	-	-	-	-	-	-	-	1	1	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
2/19	1/2 mi. E of Hatutu	YF	-	-	-	-	-	-	-	1	-	-	-	-	1	-	1	-	3	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
2/19	3/4 mi. NE of Hatutu	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	3	2	1	2	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
2/19	1/2 mi. NNW of Hatutu	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	1	2	-	1	2	1	2	-	-	1	2	2	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19
2/19	1 mi. NW of Hatutu	YF	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
2/20	1-1/2 mi. WNW of S. tip of Hatutu	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
2/20	3 mi. NW of S. tip of Hatutu	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
2/20	3 mi. SW of Eiao	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	1	-	-	-	-	-	-	-	-	-	-	-	4
2/20	1-1/2 mi. W of Eiao	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	1	-	-	1	-	-	-	-	-	-	1	-	5
2/20	4 mi. SW of Eiao	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
3/7	Clark Bank	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
3/13	Slightly NW 20-25 fa. Bank	YF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	Total	SJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	1	3	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
		YF	1	1	-	-	-	1	-	1	1	1	-	1	5	2	6	8	8	10	12	11	10	3	8	1	3	1	3	2	-	-	1	-	-	1	1	-	1	-	1	1	1	4	-	2	1	2	1	1	-	1	1	-	2	-	1	3	2	2	2	3	2	2	3	-	1	1	-	-	-	1	2	147

[1] SJ = Skipjack, YF = Yellowfin

Table 12. --Summary of bait fishing, Charles H. Gilbert cruise 43

Date, 1959	Locality	Amount seen (buckets)			No. of sets		Catch (buckets)		
		Marquesan sardine	Tahitian sardine	Tahitian nehu	Day	Night	Marquesan sardine	Tahitian sardine	Tahitian nehu
1/20	Taa Huku, Hiva Oa	-	-	-	-	-	-	-	-
1/20	Oe Hau, Tahu Ata	-	-	-	-	-	-	-	-
1/20	Motopu, Tahu Ata	-	-	-	-	-	-	-	-
1/20	Hana Hevane, Tahu Ata	1	-	-	-	-	-	-	-
1/20	Hana Tetou, Tahu Ata	38	-	-	-	-	-	-	-
1/20	Vai Tahu, Tahu Ata	20	-	-	-	-	-	-	-
1/21	Hana Menu, Hiva Oa	-	-	-	-	-	-	-	-
1/22	Tai Oa, Nuku Hiva	13 1/4	-	-	4	-	13 1/4	-	-
1/22	Taipi Vai, Nuku Hiva	3	-	-	3	-	3	-	-
1/23	Tai Oa, Nuku Hiva	9	-	-	3	-	9	-	-
1/23	Anaho, Nuku Hiva	-	-	-	-	-	-	-	-
1/23	Hatiheu, Nuku Hiva	-	-	-	-	-	-	-	-
1/24	Taipi Vai, Nuku Hiva	28	-	-	8	-	28	-	-
1/25	Taiohae, Nuku Hiva	47	-	-	4	-	47	-	-
2/8	Port Phaeton, Tahiti	-	14	20	-	2	-	14	20
2/9	Port Phaeton, Tahiti	-	-	-	1	-	-	-	-
2/10	Tautira, Tahiti	-	28	-	4	-	-	28	-
2/10	Matavai, Tahiti	-	-	-	-	-	-	-	-
2/11	Matavai, Tahiti	-	70	-	-	-	-	-	-
2/11	Papetoai, Moorea	-	10	-	-	-	-	-	-
2/11	Pao Pao, Moorea	-	27	-	-	-	-	-	-
2/12	Faaroa, Raiatea	-	3	-	-	-	-	-	-
2/12	Uturoa, Raiatea	-	-	-	-	-	-	-	-
2/13	Vaitape, Bora Bora	-	-	-	-	-	-	-	-
2/14	Fanui, Bora Bora	-	-	-	-	-	-	-	-
2/19	Taipi Vai, Nuku Hiva	21	-	-	3	-	21	-	-
2/20	Tai Oa, Nuku Hiva	32	-	-	4	-	31	-	-
2/20	Marquesienne, Nuku Hiva	-	-	-	-	-	-	-	-
2/20	Taiohae, Nuku Hiva	57	-	-	3	-	57	-	-
3/1	Tai Oa, Nuku Hiva	-	-	-	1	-	-	-	-
3/1	Taipi Vai, Nuku Hiva	-	-	-	1	-	-	-	-
3/2	Taiohae, Nuku Hiva	82	-	-	9	-	82	-	-
3/6	Hatiheu, Nuku Hiva	trace	-	-	1	-	-	-	-
3/6	Anaho, Nuku Hiva	-	-	-	-	-	-	-	-
3/6	Taipi Vai, Nuku Hiva	30	-	-	3	-	30	-	-

Table 12. --Summary of bait fishing, Charles H. Gilbert cruise 43 - continued

Date, 1959	Locality	Amount seen (buckets)			No. of sets		Catch (buckets)		
		Marquesan sardine	Tahitian sardine	Tahitian nehu	Day	Night	Marquesan sardine	Tahitian sardine	Tahitian nehu
3/11	Hana Menu, Hiva Oa	-	-	-	-	-	-	-	-
3/11	Hana Iapa, Hiva Oa	-	-	-	-	-	-	-	-
3/11	Pua Mau, Hiva Oa	5	-	-	-	-	-	-	-
3/11	Taa Huku, Hiva Oa	15	-	-	-	-	-	-	-
3/12	Hana Tetou, Tahu Ata	6	-	-	-	-	-	-	-
3/12	Hana Hevane, Tahu Ata	10	-	-	-	-	-	-	-
3/13	Haka Hetau, Hua Pou	-	-	-	-	-	-	-	-
3/13	Aneo, Hua Pou	1/4	-	-	-	-	-	-	-
3/13	Hakaehu, Nuku Hiva	50	-	-	-	-	-	-	-
3/13	Hatiheu, Nuku Hiva	25	-	-	-	-	-	-	-
3/14	Anaho, Nuku Hiva	5	-	-	-	-	-	-	-
3/14	Taipi Vai, Nuku Hiva	20	-	-	-	-	-	-	-
3/14	Tai Oa, Nuku Hiva	15	-	-	-	-	-	-	-
3/14	Taiohae, Nuku Hiva	380	-	-	1	-	28	-	-

Table 13. --Summary of bait fishing, Cape Falcon

Date 1959	Locality	Number of sets		Catch (scoops)	
		Day	Night	Anchoveta	Marquesan Sardine
1/30	Almejas Bay	-	1	174	-
1/31	Baja, California	-	8	817	-
2/1	Baja, California	-	4	1,157	-
2/2	Baja, California	-	7	166	-
2/3	Baja, California	-	5	164	-
2/4	Baja, California	-	7	266	-
2/5	Baja, California	-	4	257	-
3/10	Taipi Vai, Nuku Hiva	2	-	-	3/4
3/15	Taiohae, Nuku Hiva	4	-	-	50
	Total	6	36	3,001	50-3/4

Table 14. --Length frequency distribution of Marquesan sardines, Tahitian sardines, and Tahitian nehu, Charles H. Gilbert cruise 43

Date, 1959	Position		Fork length range in millimeters										Total
	Latitude	Longitude	35-44	45-54	55-64	65-74	75-84	85-94	95-104	105-114	115-124	125-134	
							Marquesan sardine						
1/22	08°56'S	140°10'W	-	-	8	6	2	3	-	-	-	-	19
1/22	08°56'S	140°10'W	-	-	-	-	-	-	1	7	7	1	16
1/22	08°55'S	140°04'W	-	-	-	-	1	-	3	10	3	-	17
1/23	08°56'S	140°10'W	-	1	3	7	6	4	-	-	-	-	21
1/25	08°56'S	140°07'W	-	-	3	8	5	4	2	-	-	-	22
3/2	08°56'S	140°07'W	-	-	-	-	4	18	3	-	-	-	25
3/14	08°56'S	140°07'W	-	-	-	-	7	13	4	-	-	-	24
Total				1	14	21	25	42	13	17	10	1	144
							Tahitian nehu						
2/8	17°44'S	149°20'W	-	-	4	15	9	-	1	-	-	-	29
							Tahitian sardine						
2/8, 9	17°44'S	149°20'W	1	-	-	2	2	4	6	3	2	1	21
2/10	17°44'S	149°10'W	-	-	1	2	2	8	1	4	1	1	20
2/10	17°44'S	149°10'W	8	1	11	11	-	-	-	1	1	-	33
Total			9	1	12	15	4	12	7	8	4	2	74

Table 15. --Record of daily sightings of bird flocks, scattered birds, and tuna schools, Charles H. Gilbert cruise 43

Date, 1959	Noon Position		Total number	Bird flocks									Scattered birds								Tuna schools			
				Size			Composition																	
	Latitude	Longitude		< 10	10 - 50	> 50	Terns	Boobies	Tropical birds	Frigate birds	Petrels or shearwaters	Other	Albatross	Petrels or shearwaters	Boobies	Terns	Frigate birds	Tropical birds	Storm petrels	Other	Yellowfin	Skipjack	Unidentified	Yellowfin-Skipjack
1/9	18°31'N	155°36'W	1	-	1	-	1	-	-	-	1	-	-	10	1	3	-	-	2	-	-	-	1	-
1/10	15°34'N	153°50'W	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	2	1	-	-	-	-	-
1/11	12°38'N	152°12'W	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
1/12	09°48'N	150°44'W	-	-	-	-	-	-	-	-	-	-	-	7	-	10	-	1	1	-	-	-	-	-
1/13	07°06'N	148°36'W	-	-	-	-	-	-	-	-	-	-	-	16	-	-	-	-	4	-	-	-	-	-
1/14	04°31'N	146°42'W	-	-	-	-	-	-	-	-	-	-	-	14	-	1	1	1	1	-	-	-	-	-
1/15	01°55'N	145°06'W	1	-	1	-	1	-	-	-	-	-	-	1	-	19	-	-	5	-	-	1	-	-
1/16	00°44'S	144°05'W	2	1	1	-	2	1	-	-	1	-	-	-	-	21	-	-	2	-	-	-	-	-
1/17	04°00'S	142°18'W	1	-	-	1	1	-	-	1	-	-	-	2	-	26	3	2	7	-	-	-	1	-
1/18	07°27'S	140°58'W	14	1	1	12	14	5	-	2	1	-	-	2	7	37	-	-	-	-	-	3	11	-
1/20	09°54'S	139°05'W	1	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
1/21	09°34'S	139°40'W	6	1	4	1	6	-	-	-	2	-	-	-	6	29	-	-	3	-	-	-	4	-
1/22	08°58'S	140°09'W	5	-	1	4	5	1	-	-	4	-	-	-	-	10	-	-	-	-	-	1	4	-
1/26	10°54'S	140°46'W	-	-	-	-	-	-	-	-	-	-	-	5	-	5	-	-	-	-	-	-	-	-
1/27	14°10'S	141°27'W	-	-	-	-	-	-	-	-	-	-	-	4	5	6	1	1	-	-	-	-	-	-
1/28	15°53'S	142°05'W	2	1	-	1	2	1	-	-	-	-	-	23	-	39	-	-	-	-	-	-	2	-
1/29	16°32'S	143°08'W	4	-	-	4	4	1	-	3	1	-	-	7	-	19	-	-	-	-	-	2	2	-
1/30	16°08'S	144°28'W	5	1	3	1	5	1	-	1	1	-	-	55	7	15	1	-	-	-	-	-	4	-
1/31	15°54'S	145°40'W	5	-	2	3	5	5	-	-	-	-	-	-	4	24	1	-	-	-	-	4	1	-
2/1	15°31'S	146°08'W	3	-	-	3	3	2	-	-	-	-	-	-	7	71	-	-	-	-	-	2	1	-
2/2	15°16'S	167°09'W	6	-	-	6	6	6	-	3	-	-	-	-	6	48	-	-	-	-	-	2	3	1
2/3	15°31'S	148°11'W	3	-	3	-	3	2	-	-	-	-	-	2	14	57	-	-	-	-	-	-	-	-
2/11	Pao Pao Bay, Moorea		1	-	1	-	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-
2/12	16°44'S	151°26'W	-	-	-	-	-	-	-	-	-	-	-	-	4	5	-	-	-	-	-	-	-	-
2/13	16°30'S	151°46'W	2	-	1	1	2	2	-	-	1	-	-	5	11	9	-	-	-	-	-	-	1	-
2/15	16°12'S	151°10'W	-	-	-	-	-	-	-	-	-	-	-	-	4	8	-	-	-	-	-	-	-	-
2/16	14°03'S	148°12'W	-	-	-	-	-	-	-	-	-	-	-	1	-	2	-	-	-	-	-	-	-	-
2/17	12°06'S	145°10'W	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
2/18	10°12'S	142°24'W	2	-	-	2	2	2	-	1	1	-	-	4	-	4	-	-	2	-	-	1	1	-

Table 15.--Record of daily sightings of bird flocks, scattered birds, and tuna schools, Charles H. Gilbert cruise 43 - continued

Date, 1959	Noon Position		Total number	Bird flocks									Scattered birds								Tuna schools			
				Size			Composition																	
	Latitude	Longitude		< 10	10 - 50	> 50	Terns	Boobies	Tropical birds	Frigate birds	Petrels or shearwaters	Other	Albatross	Petrels or shearwaters	Boobies	Terns	Frigate birds	Tropical birds	Storm petrels	Other	Yellowfin	Skipjack	Unidentified	Yellowfin-Skipjack
2/22	08°38'S	140°26'W	2	-	-	2	2	2	-	-	-	-	-	-	9	93	1	-	-	-	-	1	1	-
2/23	07°53'S	139°59'W	9	-	4	5	9	5	-	5	-	-	-	3	4	36	2	-	-	-	3	2	4	-
2/24	08°43'S	139°13'W	4	-	-	4	4	3	-	-	-	-	-	-	5	64	-	1	1	-	-	4	-	-
2/25	09°35'S	138°50'W	4	-	1	3	4	2	-	-	-	-	-	-	1	65	7	-	-	-	-	2	2	-
2/26	10°22'S	138°26'W	3	-	1	2	3	2	-	2	-	-	-	-	7	40	3	-	2	-	-	2	1	-
2/27	09°49'S	139°09'W	2	-	-	2	1	1	-	1	-	-	-	14	6	49	1	-	-	-	-	2	-	-
2/28	09°33'S	140°02'W	2	-	1	1	2	1	-	-	-	-	-	12	2	48	2	-	-	-	-	1	1	-
3/1	08°55'S	140°02'W	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	2	2	-	-	-	-	-
3/3	08°24'S	139°40'W	1	-	-	1	1	1	-	-	-	-	-	-	16	68	3	-	5	-	-	-	-	1
3/4	05°38'S	139°42'W	3	-	3	-	3	-	-	-	-	-	-	1	-	14	1	-	-	-	-	-	-	-
3/5	07°15'S	139°46'W	6	-	1	5	6	6	-	1	-	-	-	2	2	13	1	-	2	-	-	4	2	-
3/8	09°52'S	139°36'W	3	-	1	2	3	3	-	1	-	-	-	5	5	25	1	-	2	-	1	2	-	1
3/9	12°32'S	139°47'W	-	-	-	-	-	-	-	-	-	-	-	1	-	9	-	-	-	-	-	-	-	-
3/10	10°54'S	139°38'W	4	-	1	3	4	3	-	2	1	-	-	4	1	22	-	3	-	-	-	1	-	1
3/12	09°38'S	139°48'W	3	-	-	3	3	3	-	2	-	-	-	2	2	46	-	-	1	-	-	2	1	-
3/13	08°56'S	139°15'W	2	-	1	1	2	-	-	-	-	-	-	-	-	98	-	-	-	-	-	-	1	-
3/14	08°58'S	140°09'W	1	-	1	-	1	1	-	-	-	-	-	-	3	23	-	-	-	-	-	-	1	-
3/16	08°52'S	140°16'W	4	-	-	4	4	4	-	-	-	-	-	-	5	31	-	-	-	-	-	1	3	-
3/17	05°34'S	142°18'W	-	-	-	-	-	-	-	-	-	-	-	-	2	12	-	-	-	-	-	-	-	-
3/18	02°25'S	144°21'W	-	-	-	-	-	-	-	-	-	-	-	1	-	6	-	-	1	-	-	-	-	-
3/19	00°01'S	145°46'W	-	-	-	-	-	-	-	-	-	-	-	2	-	4	-	-	1	-	-	-	-	-
3/20	03°36'N	147°38'W	-	-	-	-	-	-	-	-	-	-	-	-	3	6	-	-	5	-	-	-	-	-
3/21	06°48'N	148°53'W	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	1	-	-	-	-	-
3/22	10°16'N	150°20'W	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	1	-	-	-	-	-
3/23	13°39'N	152°08'W	1	-	1	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	1	-
3/24	16°58'N	153°38'W	-	-	-	-	-	-	-	-	-	-	1	21	-	-	-	-	7	-	-	-	-	-
3/25	18°36'N	155°51'W	-	-	-	-	-	-	-	-	-	-	1	15	-	13	-	2	-	-	-	-	-	-
3/26	Honolulu		-	-	-	-	-	-	-	-	-	-	5	12	8	-	-	-	-	-	-	-	-	-

Table 16.--Record of daily sightings of bird flocks, scattered birds, and tuna schools, Cape Falcon

Date, 1959	Noon Position		Total number	Bird flocks									Scattered birds								Tuna schools			
				Size			Composition																	
	Latitude	Longitude		< 10	10 - 50	> 50	Terns	Boobies	Tropical birds	Frigate birds	Petrels or shearwaters	Other	Albatross	Petrels or shearwaters	Boobies	Terns	Frigate birds	Tropical birds	Storm petrels	Other	Yellowfin	Skipjack	Unidentified	Mixed
2/6	21°23'N	114°48'W	-	-	-	-	-	-	-	-	-	-	-	2	-	-	4	-	2	-	-	-	-	-
2/7	18°48'N	117°01'W	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	7	-	-	-	-	-
2/8	15°50'N	118°54'W	-	-	-	-	-	-	-	-	-	-	-	2	3	-	-	-	9	-	-	-	-	-
2/9	12°57'N	120°37'W	1	-	-	1	1	-	-	-	1	-	-	4	-	-	-	1	5	-	-	1	-	-
2/10	10°04'N	122°30'W	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	2	-	-	-	-	-
2/11	07°06'N	124°15'W	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	6	-	-	-	-	-
2/12	04°10'N	125°03'W	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	2	-	-	-	-	-
2/13	01°19'N	126°57'W	3	2	1	-	3	-	-	-	-	-	-	1	-	-	-	-	3	-	-	-	1	-
2/14	01°39'S	128°55'W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-
2/15	05°04'S	130°55'W	4	1	2	1	4	-	-	1	-	-	-	4	-	-	-	-	-	-	-	-	1	-
2/16	06°12'S	134°09'W	12	4	7	1	12	-	-	2	-	-	-	1	-	11	-	1	17	-	-	1	3	-
2/17	07°21'S	137°37'W	12	5	5	2	12	3	-	-	3	-	-	2	-	20	4	-	1	-	1	3	1	-
2/18	07°54'S	139°58'W	22	4	10	8	22	6	-	5	8	-	-	2	3	21	-	-	1	-	7	3	7	3[1]
2/19	07°52'S	140°20'W	19	1	9	9	19	6	-	4	4	-	-	9	14	92	6	-	1	-	6	1	5	4[2]
2/20	08°02'S	140°46'W	24	-	8	16	24	12	-	13	1	-	-	-	-	20	-	-	-	-	9	7	2	3[3]
2/21	08°36'S	140°06'W	11	1	6	4	11	1	1	4	-	-	-	2	9	131	5	1	-	-	1	2	3	-
2/22	09°23'S	139°59'W	14	-	10	4	14	3	-	4	-	-	-	20	6	226	1	-	2	-	2	4	3	1[3]
2/23	12°42'S	140°40'W	3	-	3	-	3	-	-	2	-	-	-	1	-	6	-	-	-	-	-	-	1	-
2/24	14°04'S	141°29'W	7	2	5	-	7	-	-	4	-	-	-	-	-	68	5	-	-	-	1	1	1	-
2/25	16°13'S	142°46'W	8	2	4	2	8	4	-	3	-	-	-	2	3	140	3	-	-	-	2	-	1	-
2/26	16°47'S	144°10'W	11	3	5	3	10	8	-	-	-	-	-	4	51	98	11	-	-	-	-	1	2	-
2/27	17°13'S	147°34'W	5	-	4	1	5	2	-	-	2	-	-	-	1	21	-	-	-	-	-	2	2	-
3/1	17°10'S	149°09'W	2	1	-	1	2	1	-	-	-	-	-	1	3	32	-	-	-	-	-	-	1	-
3/2	14°57'S	146°38'W	11	4	4	3	11	3	-	4	1	-	-	-	4	62	2	-	-	-	-	2	2	-
3/3	12°51'S	144°27'W	2	1	1	-	2	-	-	2	1	-	-	1	-	3	-	-	-	-	-	1	-	-
3/4	10°25'S	142°19'W	2	-	1	1	2	1	-	1	-	-	-	-	-	2	-	-	1	-	1	-	-	-

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[1] 2 yellowfin-skipjack, 1 yellowfin-skipjack-little tuna

[2] 3 yellowfin-skipjack, 1 yellowfin-little tuna

[3] Yellowfin-skipjack

Table 16. --Record of daily sightings of bird flocks, scattered birds, and tuna schools, Cape Falcon - continued

Date, 1959	Noon Position		Total number	Bird flocks									Scattered birds								Tuna schools			
				Size			Composition																	
	Latitude	Longitude		< 10	10 - 50	> 50	Terns	Boobies	Tropical birds	Frigate birds	Petrels or shearwaters	Other	Albatross	Petrels or shearwaters	Boobies	Terns	Frigate birds	Tropical birds	Storm petrels	Other	Yellowfin	Skipjack	Unidentified	Mixed
3/5	08°40'S	140°37'W	20	3	8	9	20	10	-	2	1	-	-	3	29	90	11	-	-	-	4	2	5	4[4/]
3/6	07°58'S	140°07'W	18	5	7	6	18	9	-	4	1	-	-	6	24	331	1	-	3	-	5	1	5	-
3/7	08°07'S	139°37'W	20	-	14	6	20	9	-	5	1	-	-	4	-	55	-	-	4	-	3	3	6	4[5/]
3/8	08°49'S	140°03'W	2	1	1	-	2	-	-	-	-	-	-	1	8	168	-	1	6	-	-	-	-	-
3/9	08°49'S	139°55'W	1	-	1	-	1	-	-	-	-	-	-	-	-	20	-	-	-	-	-	1	-	-
3/10	08°57'S	139°59'W	8	2	2	4	8	3	-	1	-	-	-	-	7	102	6	2	-	-	1	1	-	2[3/]
3/11	08°53'S	140°02'W	6	-	4	2	6	2	-	1	-	-	-	-	-	12	-	-	-	-	1	3	1	-
3/12	08°48'S	139°12'W	16	5	5	6	16	8	1	1	-	-	-	2	13	88	-	-	3	-	1	4	4	1[3/]
3/13	07°54'S	139°57'W	13	3	8	2	13	3	-	1	-	-	-	5	7	159	-	1	4	-	10	-	2	2[6/]
3/14	08°37'S	140°10'W	8	2	4	2	6	2	1	-	2	-	-	7	14	130	-	-	2	-	-	1	1	1[3/]

[3/] Yellowfin-skipjack

[4/] 1 yellowfin-skipjack 1 yellowfin-dogtooth tuna, 1 yellowfin-dolphin, 1 yellowfin-rainbow runner

[5/] 2 yellowfin-unidentified, 1 yellowfin-little tuna-rainbow runner, 1 little tuna-rainbow runner

[6/] 1 yellowfin-little tuna, 1 yellowfin-rainbow runner

Table 17.--Record of aquatic mammals sighted, Charles H. Gilbert cruise 43

Date, 1959	Position		Time LT	Observation	Number
	Latitude	Longitude			
1/16	01°06'S	143°52'W	1455	Whale	1
1/16	01°18'S	143°45'W	1615	"	1
2/1	16°03'S	145°43'W	0625	Porpoise	20
2/22	08°59'S	140°11'W	0915	"	6
2/22	08°14'S	140°40'W	1550	"	2
2/23	07°56'S	139°53'W	1240	"	4
2/24	08°48'S	139°17'W	1045	"	1
2/24	08°56'S	139°27'W	1500	"	12
2/25	09°24'S	139°02'W	0950	"	8
3/1	08°56'S	140°04'W	1007	"	15
3/5	06°37'S	139°51'W	0640	Whale	1
3/8	09°54'S	139°35'W	1215	Blackfish	4
3/13	09°21'S	140°07'W	0550	Porpoise	20
3/13	09°02'S	140°12'W	1105	"	9
3/13	08°52'S	140°15'W	1224	"	4
3/13	08°46'S	140°09'W	1430	"	2
3/17	04°47'S	142°50'W	1800	"	very large school

Table 18.--Record of aquatic mammals sighted, Cape Falcon

Date, 1959	Position		Time LT	Observation	Number
	Latitude	Longitude			
2/12	03°48'N	125°12'W	1300	Blackfish	2
2/16	06°22'S	134°31'W	1425	"	2
2/18	07°54'S	139°58'W	1248	Porpoise	large school
2/21	08°31'S	140°12'W	0800-0830	"	-
2/22	09°10'S	140°03'W	0930	"	large school
2/22	09°34'S	140°06'W	1415	"	10
2/25	16°14'S	142°56'W	1443	"	few
3/4	10°36'S	142°28'W	1020	Whale	2
3/5	08°48'S	140°46'W	1025	Porpoise	few
3/8	08°45'S	140°02'W	1010	"	large school
3/9	08°45'S	140°03'W	0615	"	50
3/10	08°45'S	140°14'W	0625	"	few
3/10	08°48'S	140°15'W	0750	"	large school
3/12	08°50'S	139°15'W	1130	"	approx. 30
3/13	08°02'S	139°44'W	0900-0910	Blackfish	2
3/13	08°02'S	139°44'W	0936	Whale	1
3/14	08°32'S	140°08'W	1123	Blackfish	12

Table 19.--Common and scientific names of fish caught

Anchoveta	*Cetengraulis mysticetus* (Günther)
Barracuda	*Sphyraena nigripinnis* Temminck and Schlegel
Bigeye tuna	*Parathunnus sibi* (Temminck and Schlegel)
Dogtooth tuna	*Gymnosarda nuda* (Günther)
Dolphin	*Coryphaena hippurus* Linnaeus
Green snapper	*Aprion virescens* Cuvier and Valenciennes
Jack	*Caranx ignobilis* (Forskål)
Jack	*Caranx lugubris* Poey
Jack	*Caranx melampygus* Cuvier and Valenciennes
Little tuna	*Euthynnus yaito* Kishinouye
Marquesan sardine	*Harengula vittata* (Cuvier and Valenciennes)
Rainbow runner	*Elagatis bipinnulatus* (Quoy and Gaimard)
Skipjack	*Katsuwonus pelamis* (Linnaeus)
Tahitian nehu	*Stolephorus* sp.
Tahitian sardine	*Sardinella melanosticta* (Schlegel)
Wahoo	*Acanthocybium solandri* (Cuvier and Valenciennes)
Yellowfin tuna	*Neothunnus macropterus* (Temminck and Schlegel)

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